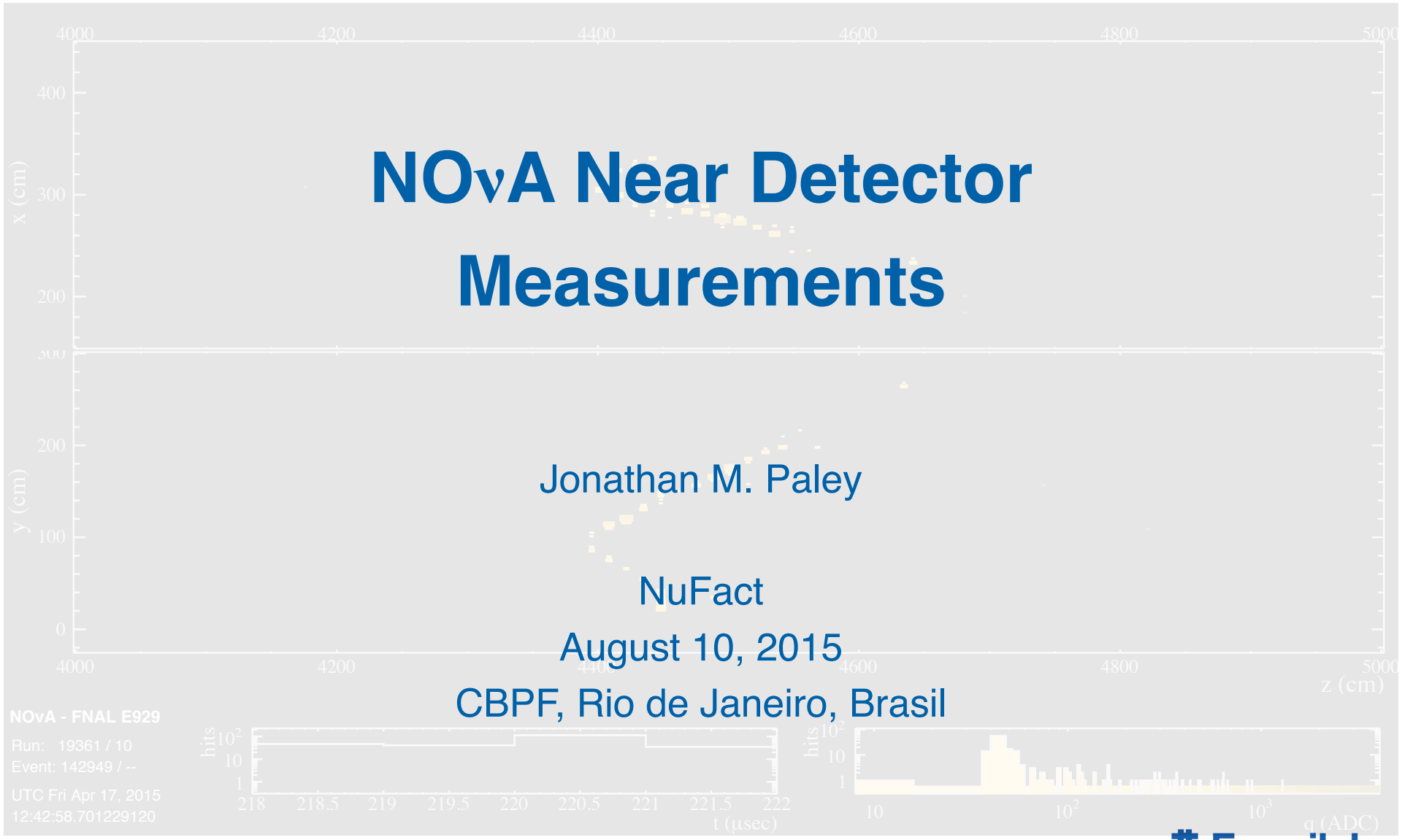
NOvA Near Detector Measurements

Jonathan M. Paley

NuFact

August 10, 2015

CBPF, Rio de Janeiro, Brasil



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The NOvA Collaboration

A growing collaboration of over 200 scientists and engineers from 38 institutions and 7 countries.

Overview of this talk

- Overview of detectors and beam
- The role of ND measurements in NOνA
- ND measurements in NOνA's first oscillation results
- ND-specific analyses underway

- See Mayly Sanchez's presentation tomorrow (Tuesday, Aug. 11) of NOνA's first oscillation results!

The NuMI Off-Axis ν_e Appearance (NOνA) Experiment

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The NuMI Off-Axis ν_e Appearance (NOνA) Experiment

Ash River, MN

14 kton, 810 km,
14 mrad off-axis

NOvA Far Detector

MINOS Far Detector

Existing NuMI
Beam from FNAL

Upgrade from 330 kW to
700 kW in progress

Ontario

Wisconsin

Iowa

Milwaukee

Nearly identical 300 ton detector located at FNAL, 14 mrad off-axis & 1 km from source will measure ν spectrum before oscillations occur.

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Chicago

The NuMI Off-Axis ν_e Appearance (NOνA) Experiment

NOvA Far Detector

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Chicago

Existing NuMI Beam from FNAL

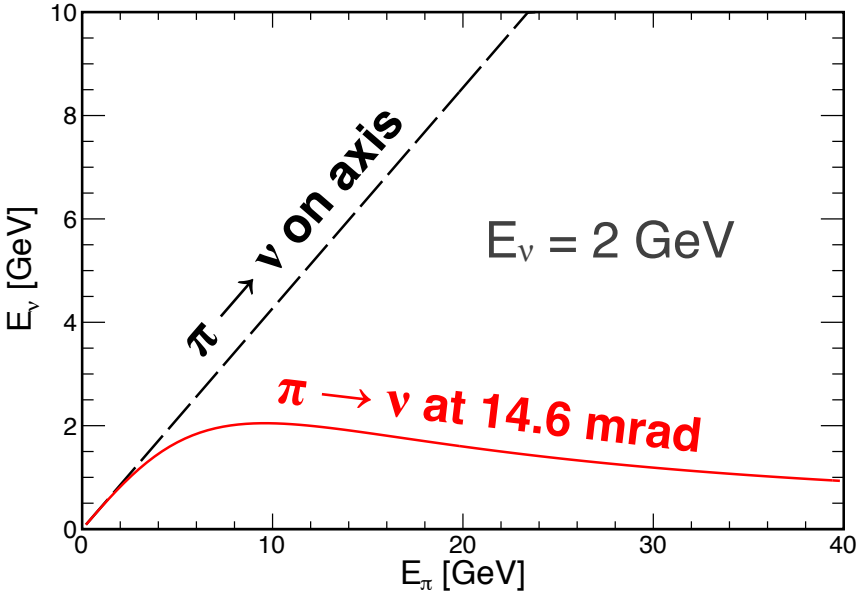
Upgrade from 330 kW to 700 kW in progress

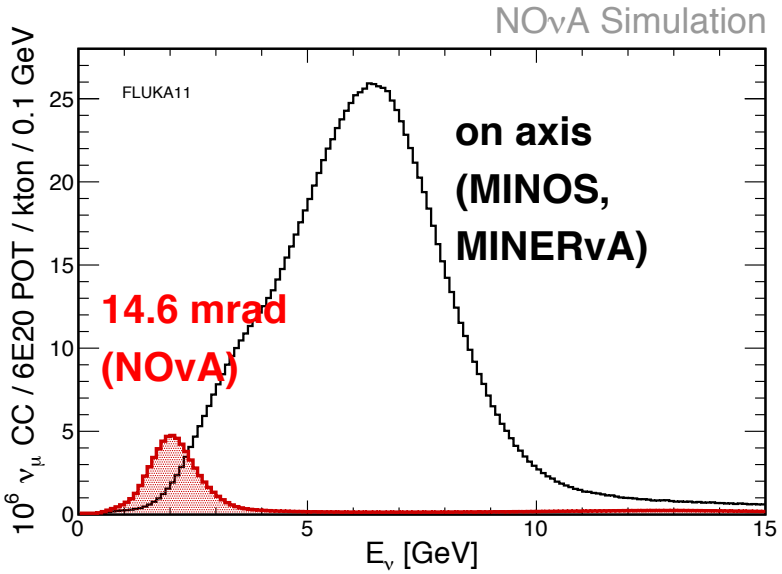
- **Goals:**
- **Observe $\nu_\mu \rightarrow \nu_e$ and measure the mixing angle θ_{13} .**
- **Resolution of the neutrino mass hierarchy**
- **Search for CP violation in the neutrino sector**
- **Improved measurements of $\sin^2(2\theta_{23})$ to within a few percent.**
- **Determine the octant of θ_{23}**

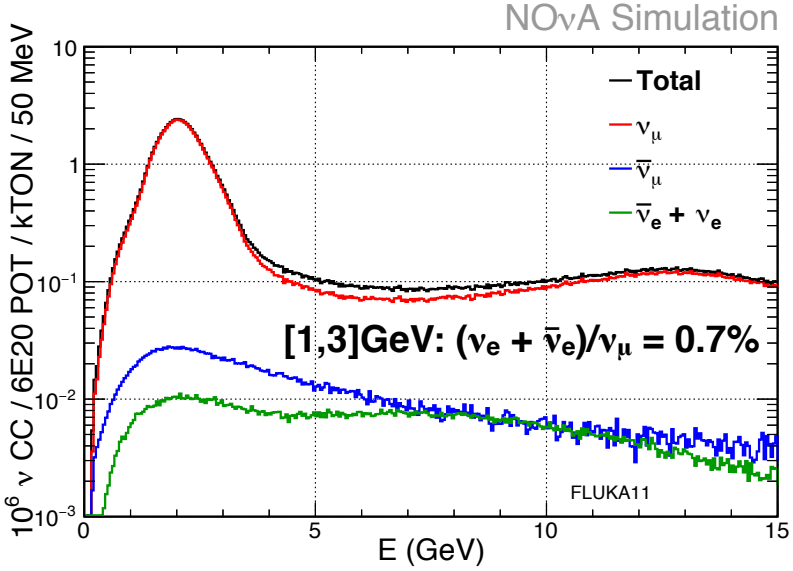
Nearly identical 300 ton detector located at FNAL, 14 mrad off-axis & 1 km from source will measure ν spectrum before oscillations occur.

The NuMI Beam

$$E_\nu = \frac{1-(m_\mu/m_\pi)^2}{1+\gamma^2\tan^2\theta}E_\pi$$







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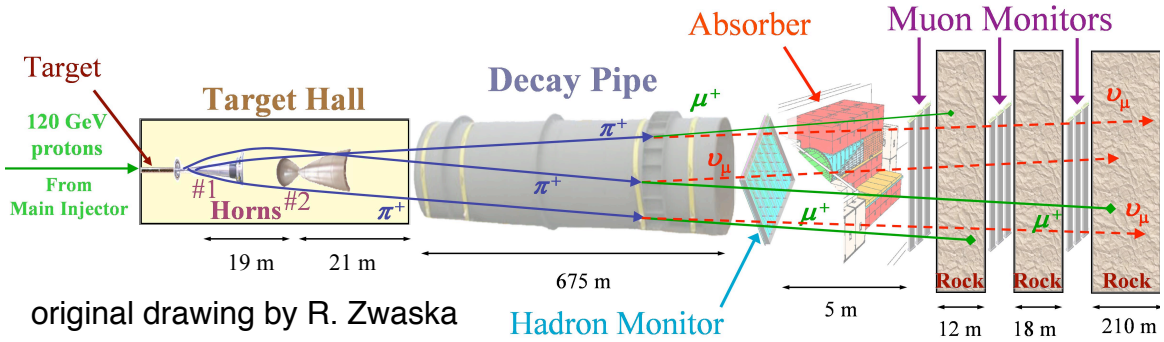
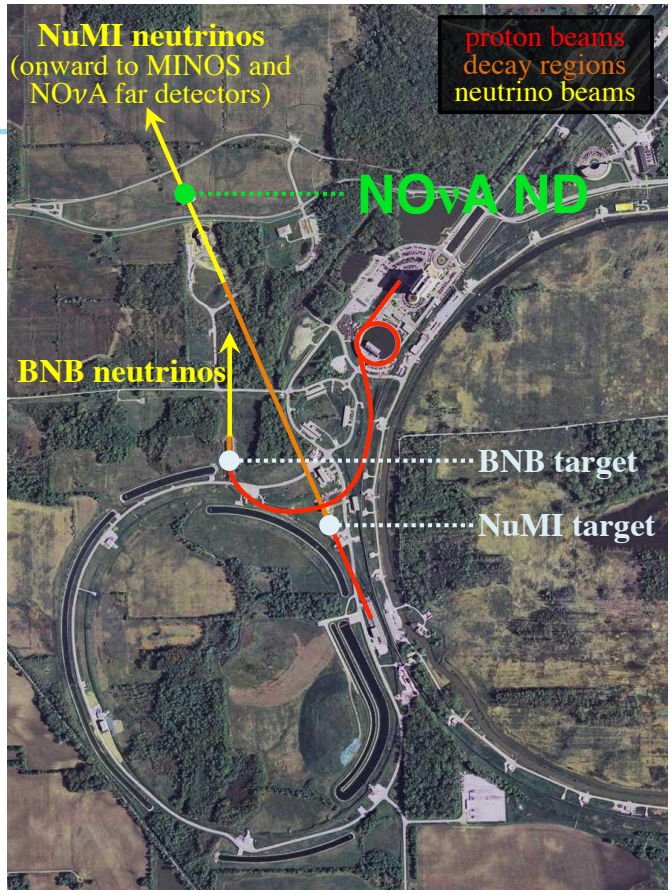
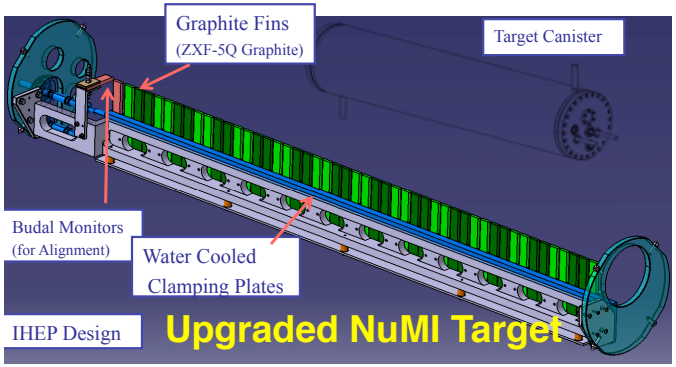
The NuMI Beam



original drawing by R. Zwaska





- NuMI upgrades:
  - use Recycler for slip-stacking protons (instead of storing $\bar{p}$)
  - Main Injector cycle time reduced from 2.2s to 1.33s
    - RF, power supply upgrades
    - New/upgraded kickers and instrumentation
  - upgrades to target station to handle increased power
- Routine 2+6 batches slip-stacking since March 2015
- Record beam power recorded: 521 kW
- Very impressive uptime: 85%
- Progress has been very smooth, all milestones of upgrades have been on time

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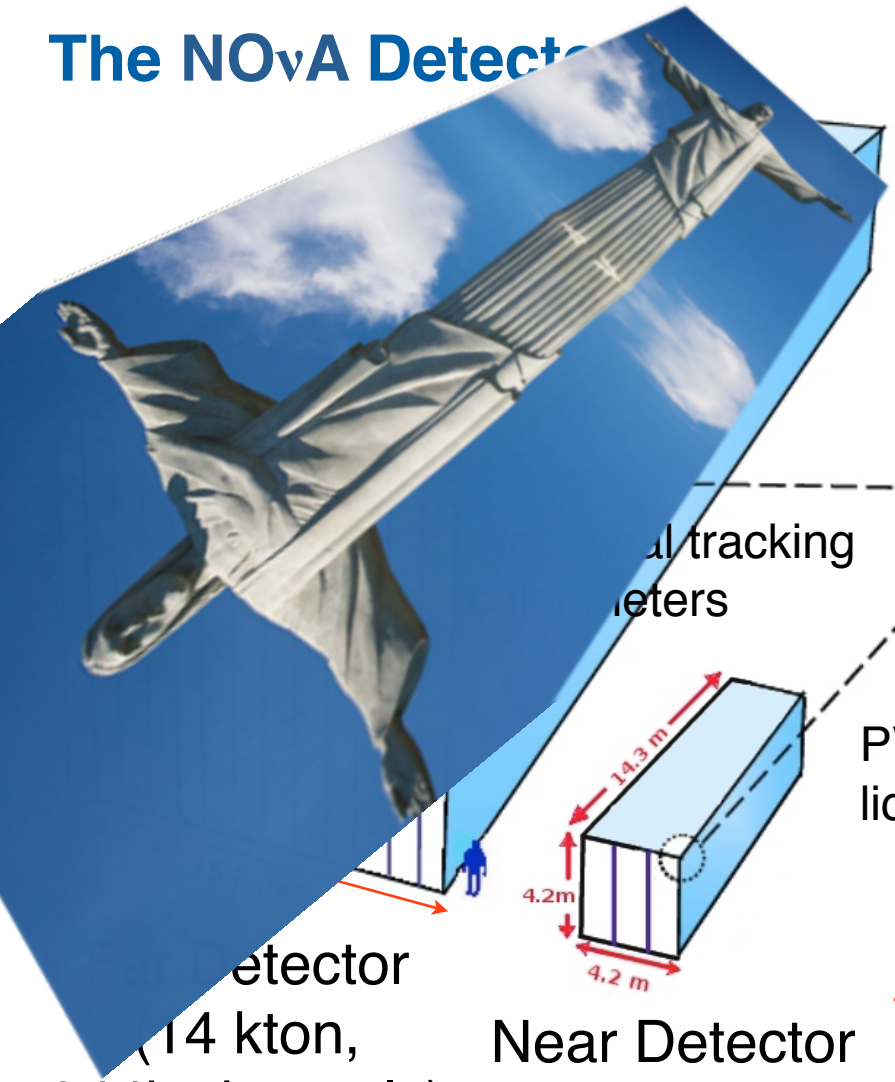
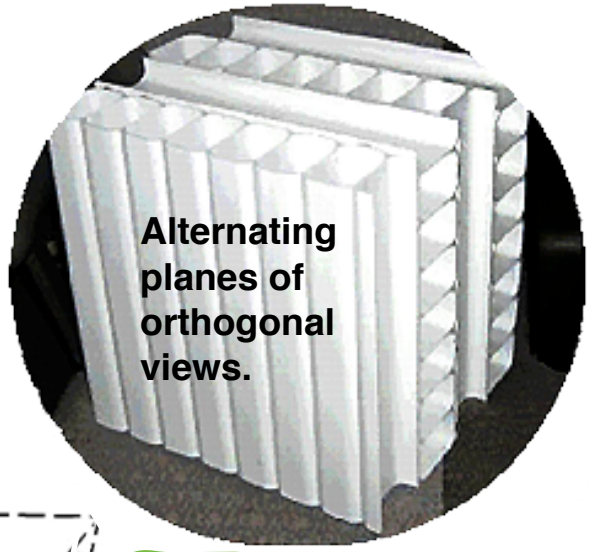
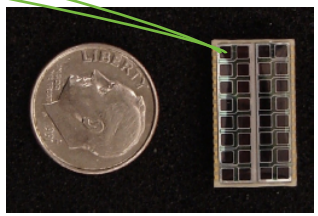
The NOvA Detect





Wavelength-shifting fibers route scint. light to avalanche photodiode (APD)



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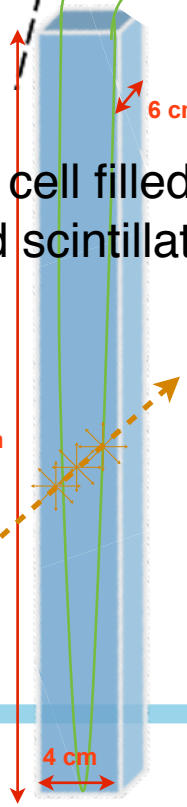
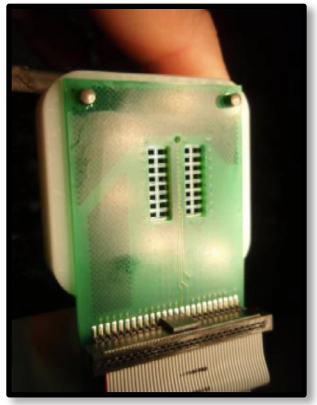
PVC cell filled with liquid scintillator





etector
(14 kton,
344k channels)

Near Detector
(0.3 kton,
20k channels)

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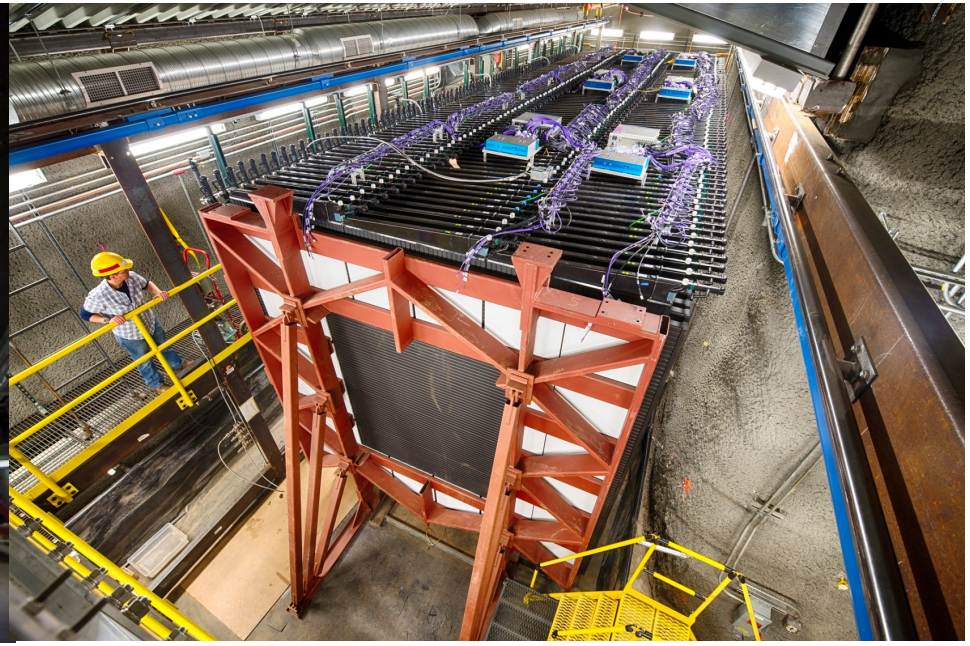
NOvA Near Detector Construction

- Detector construction and instrumentation completed Aug. 2014
- Neutrinos observed within seconds of turning on!



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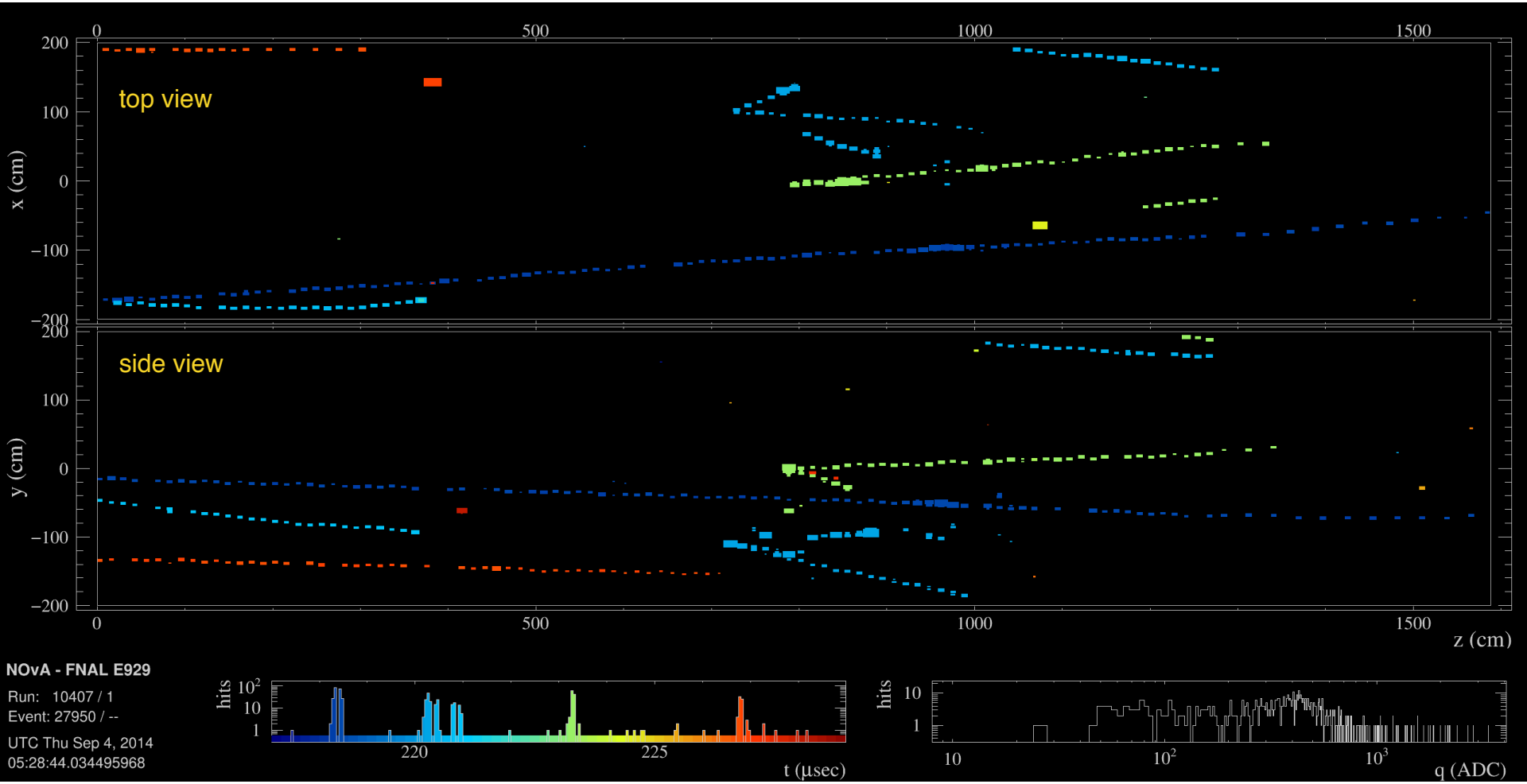
Neutrinos in the NOνA Near Detector



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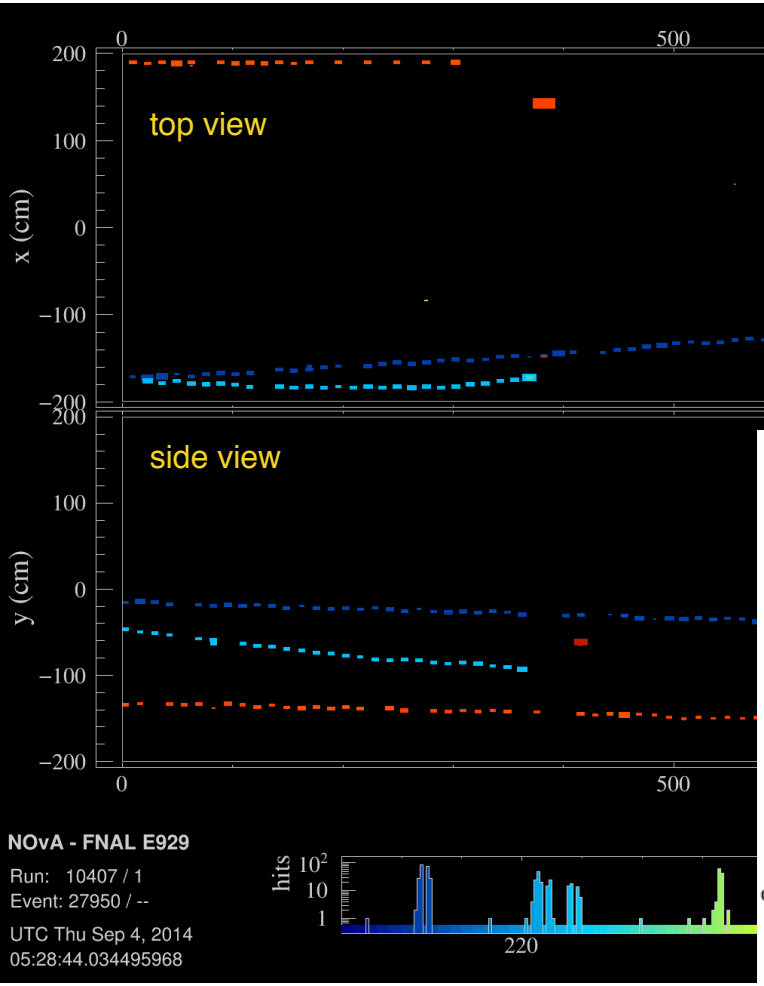
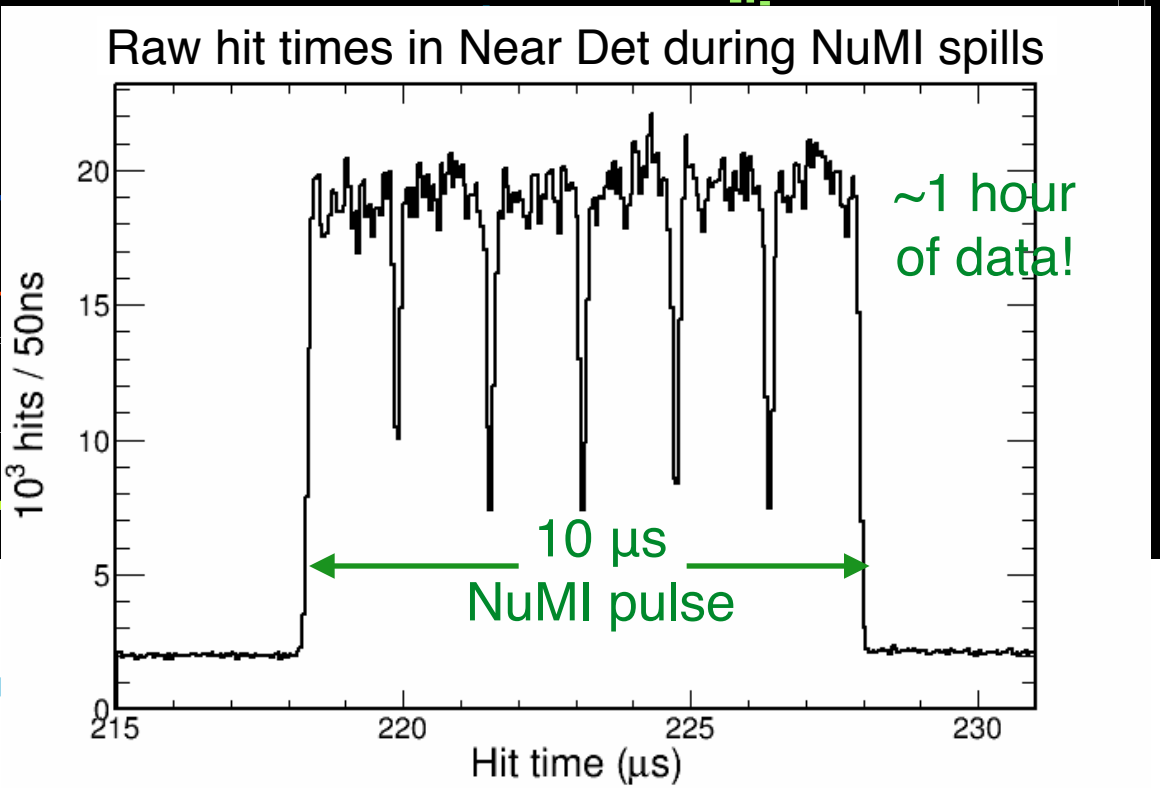
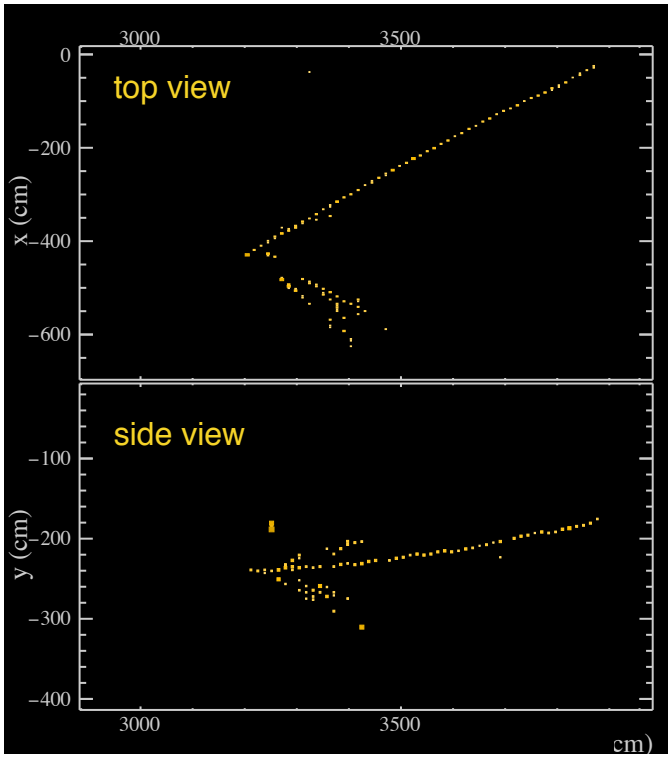
Neutrinos in the NOνA Near Detector





The Role of the Near Detector in Oscillation Analyses



- With large statistics and good resolution comes big challenges!
- Comparisons between data and MC highlight our ignorance…
- [Which is of course why we build 2-detector experiments for oscillations…]

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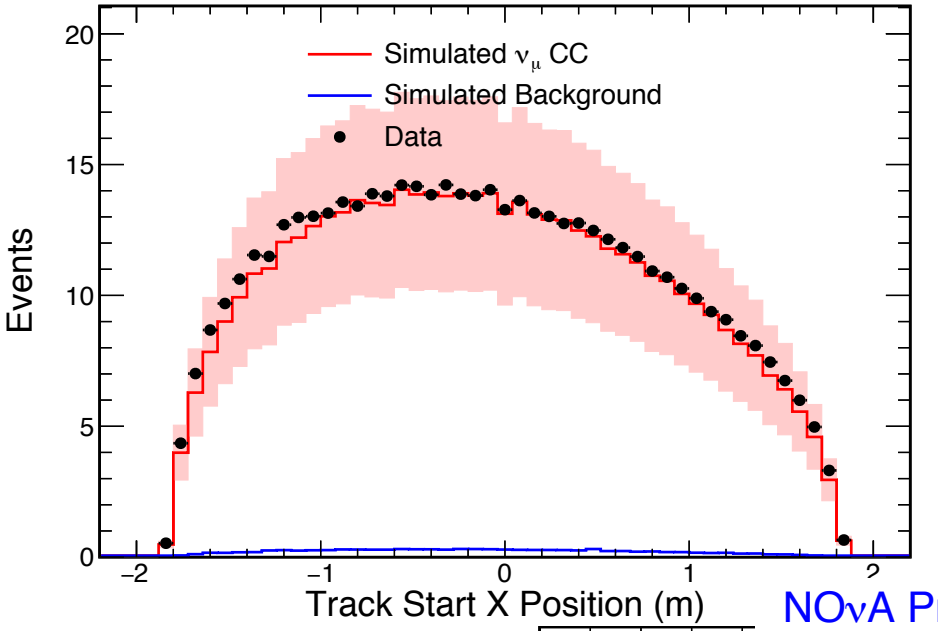
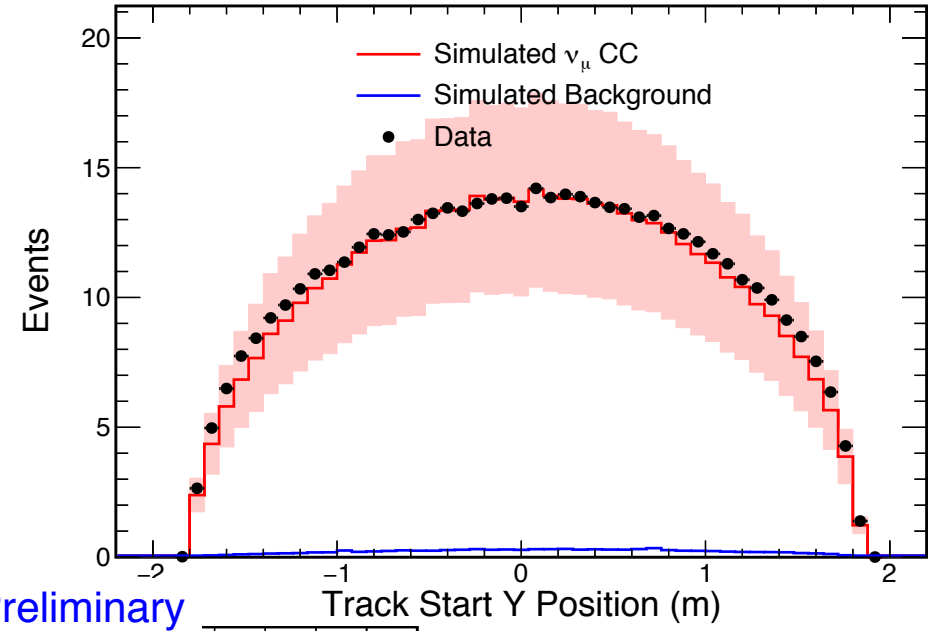
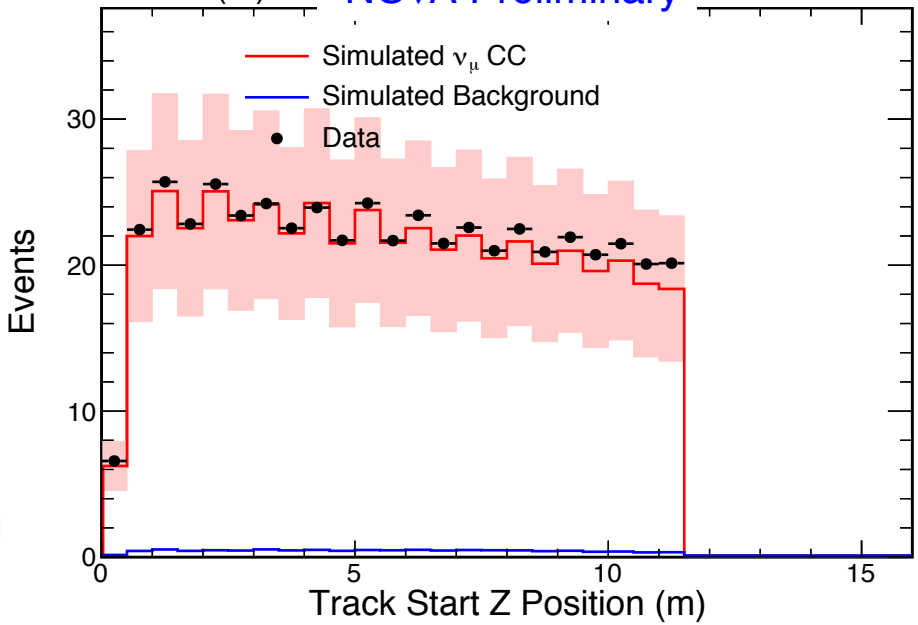
Near Detector Data/MC Comparisons





NOνA Preliminary



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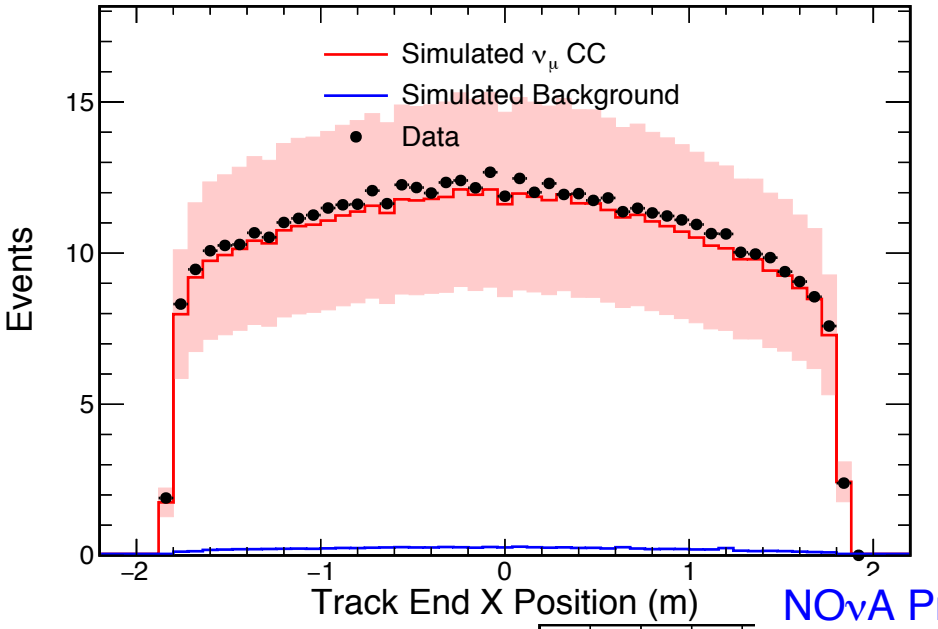
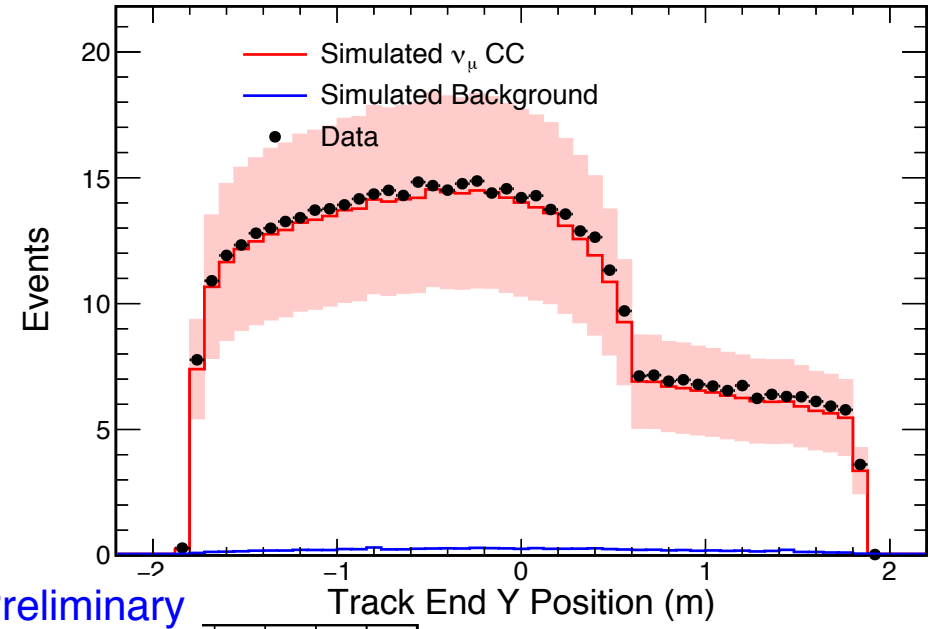
Near Detector Data/MC Comparisons





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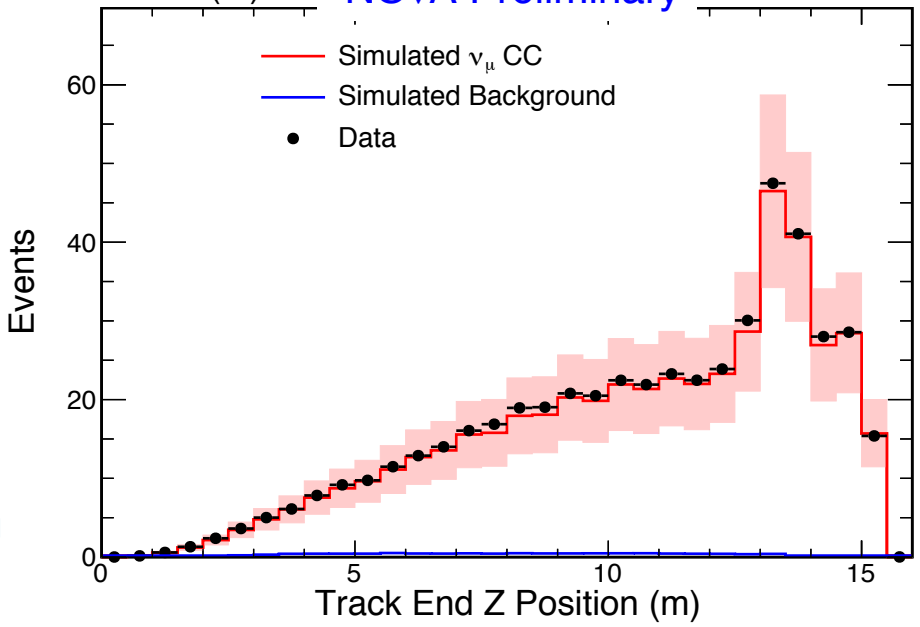

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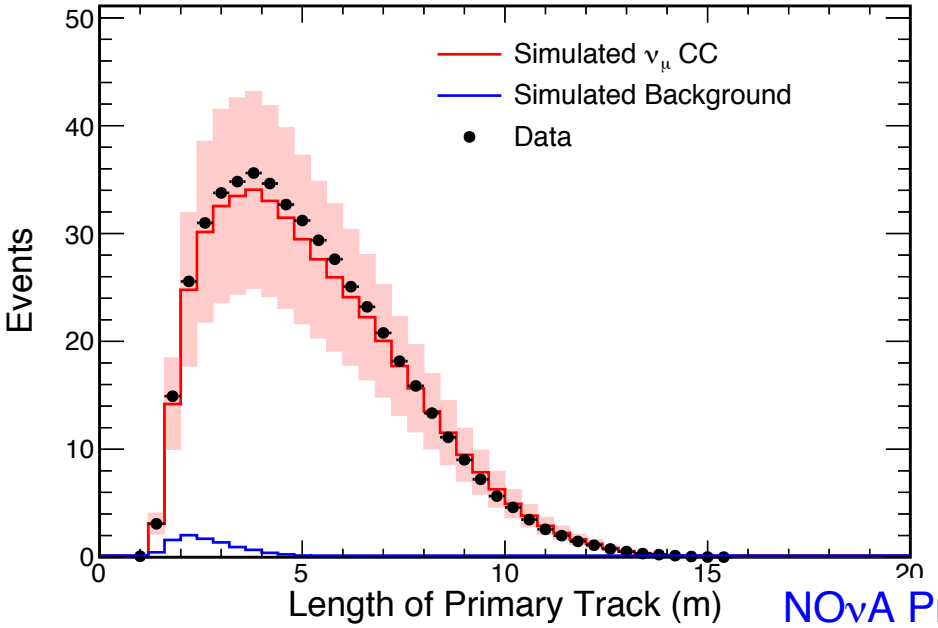

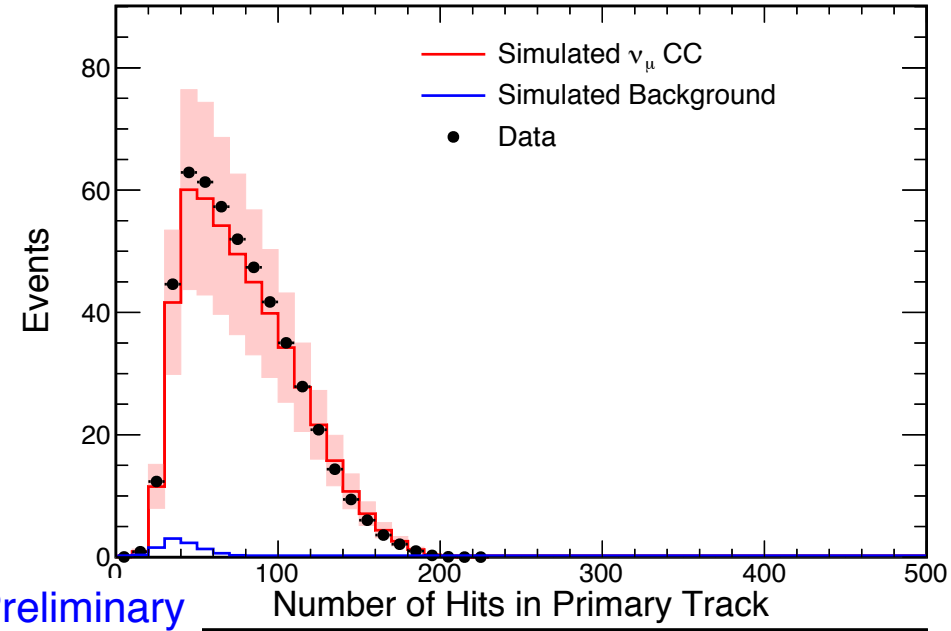

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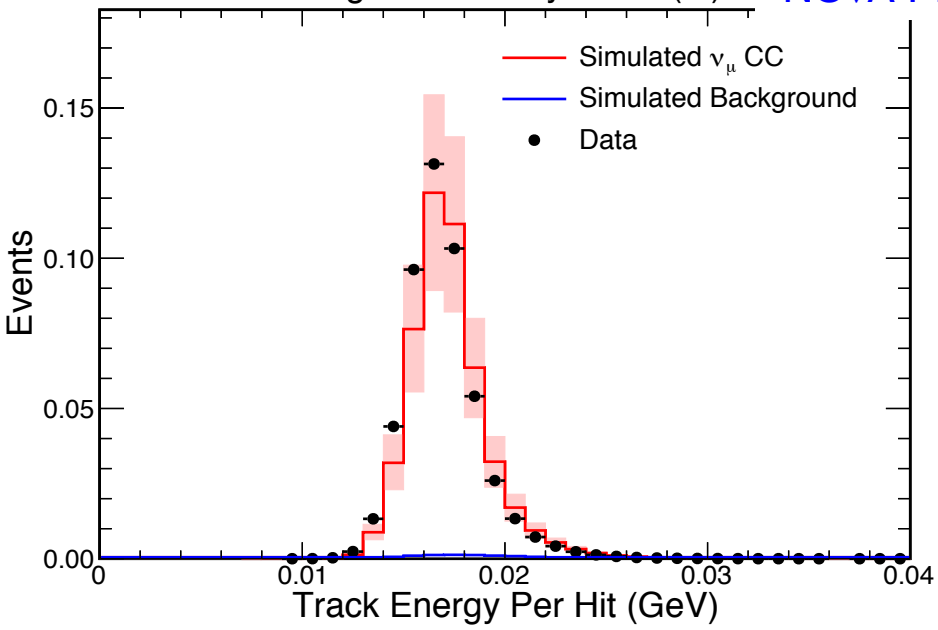

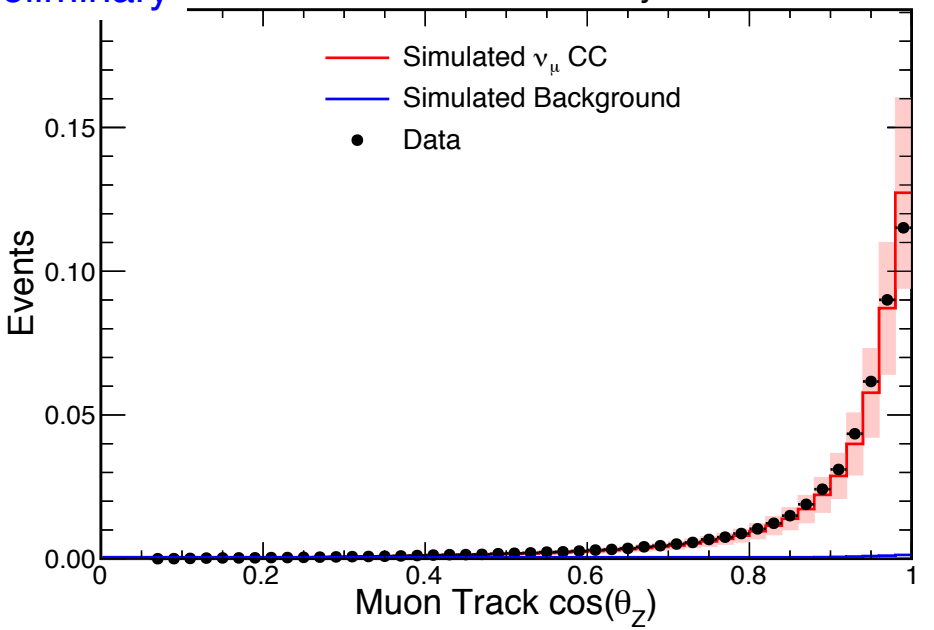

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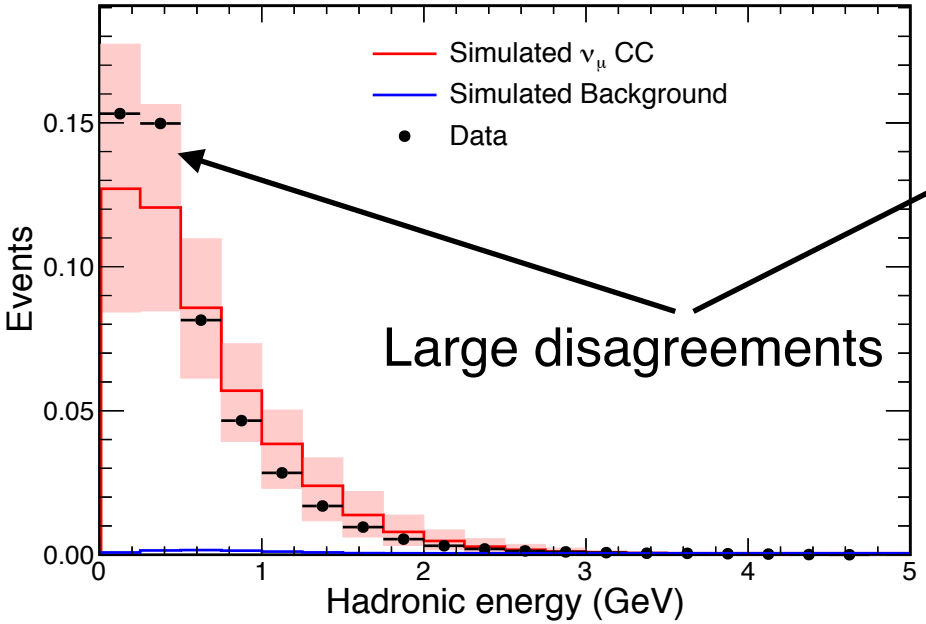
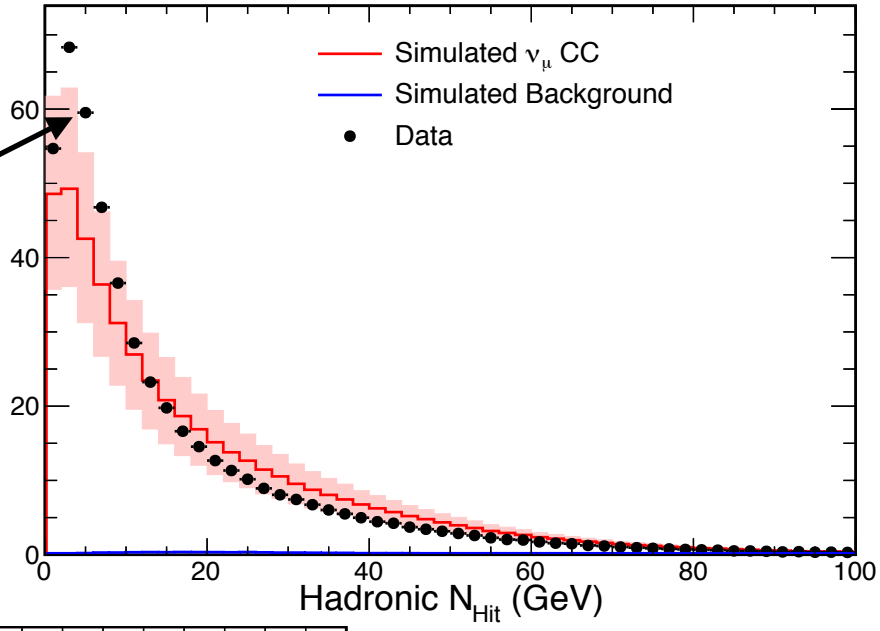
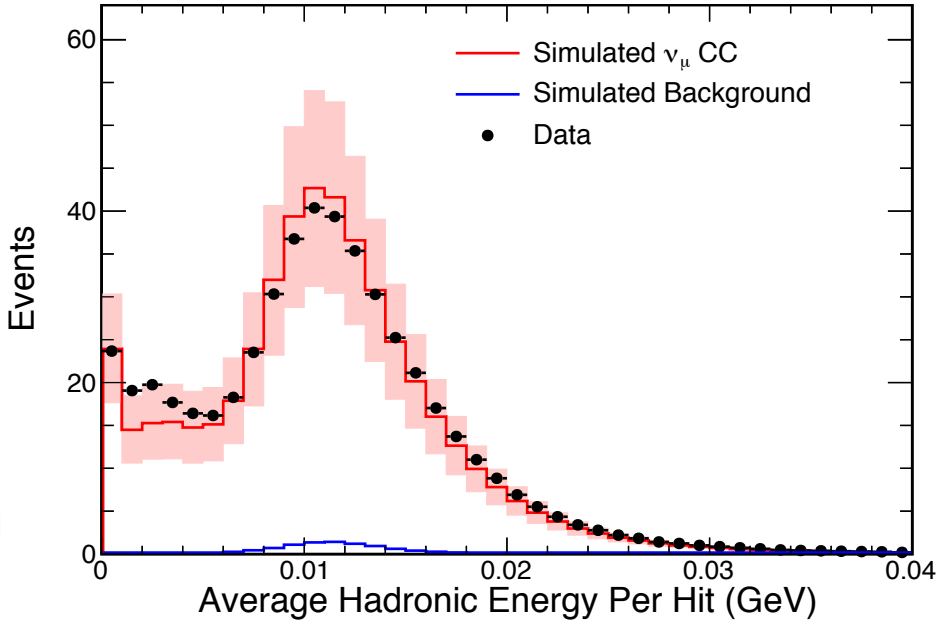


Large disagreements





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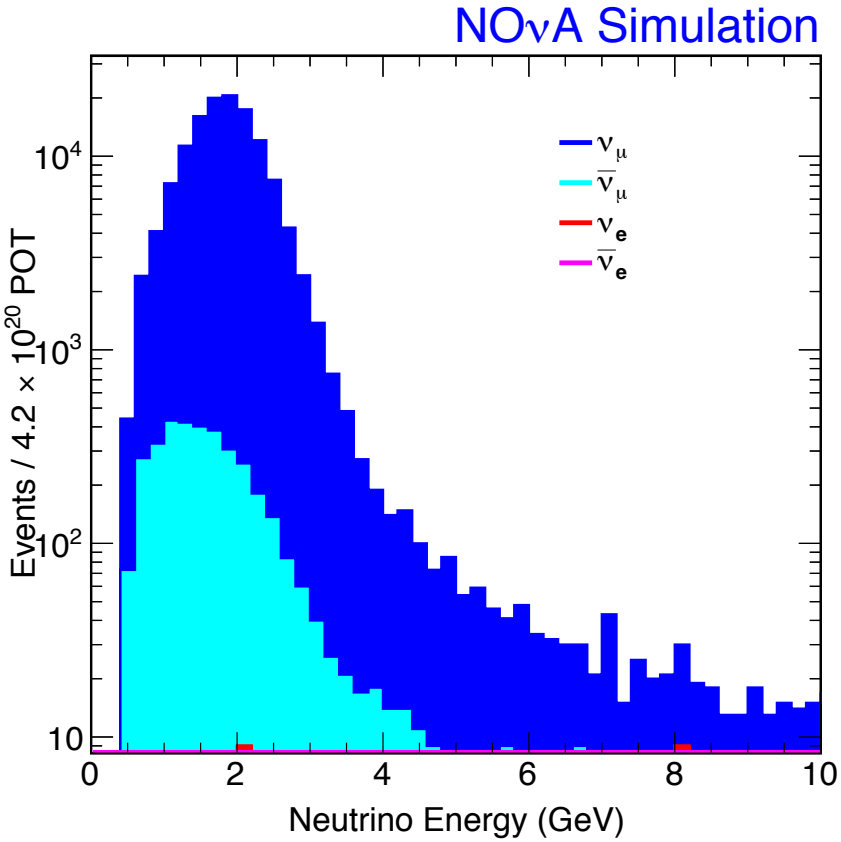
Final State Interaction Modeling

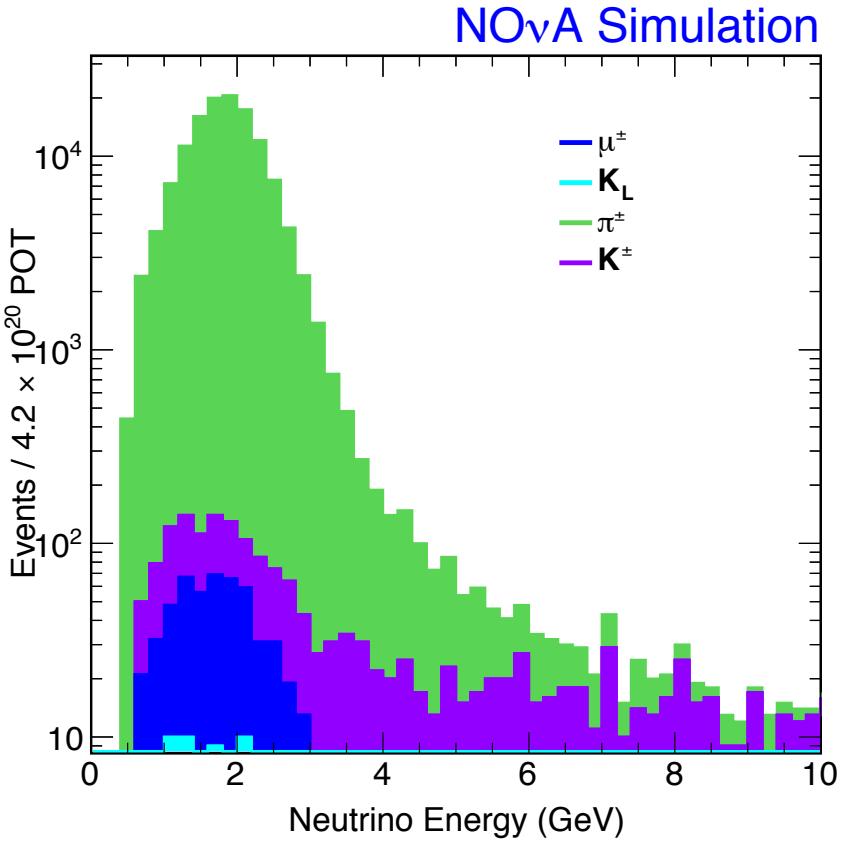
- NOνA uses the GENIE v2.8.0 MC to simulate neutrino-nucleus interactions
- The observed discrepancy is not shocking…
- Most notably, GENIE lacks a model for 2p2h FSI
- MC is used to calibrate energy deposited by FSI hadrons
- Effect mostly cancels out in 2-detector oscillation analyses, but is largest systematic uncertainty in the disappearance analysis
- We're looking forward to upcoming changes to GENIE that will allow us to do some detailed tests of more advanced FSI models

Analyses Underway

- ν_μ CC
- ν_e + A
- ν + e
- Coherent π^0
- … and many others getting started!

ν_μ CC Interactions in the NOνA Near Detector





Very pure ν_μ selection!

Shape of spectrum from 3-6 GeV could give insights into K/π production in NuMI target.

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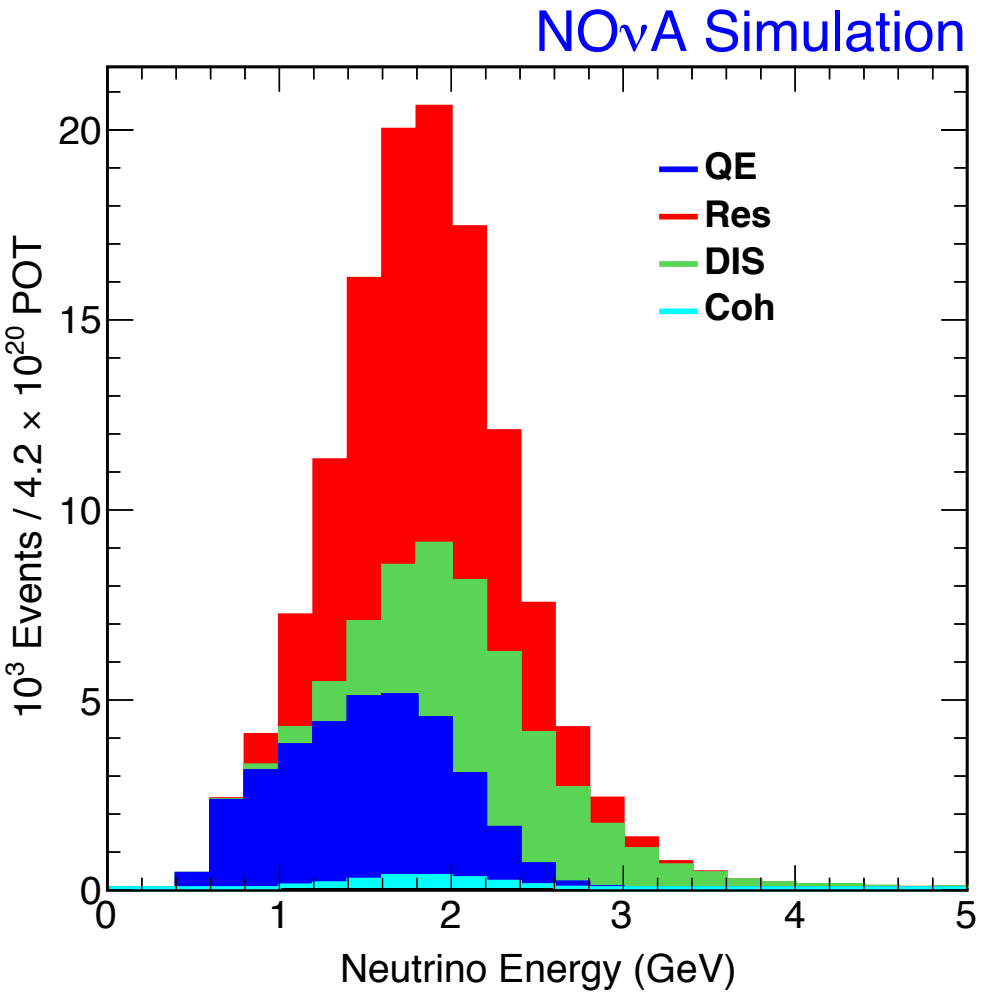
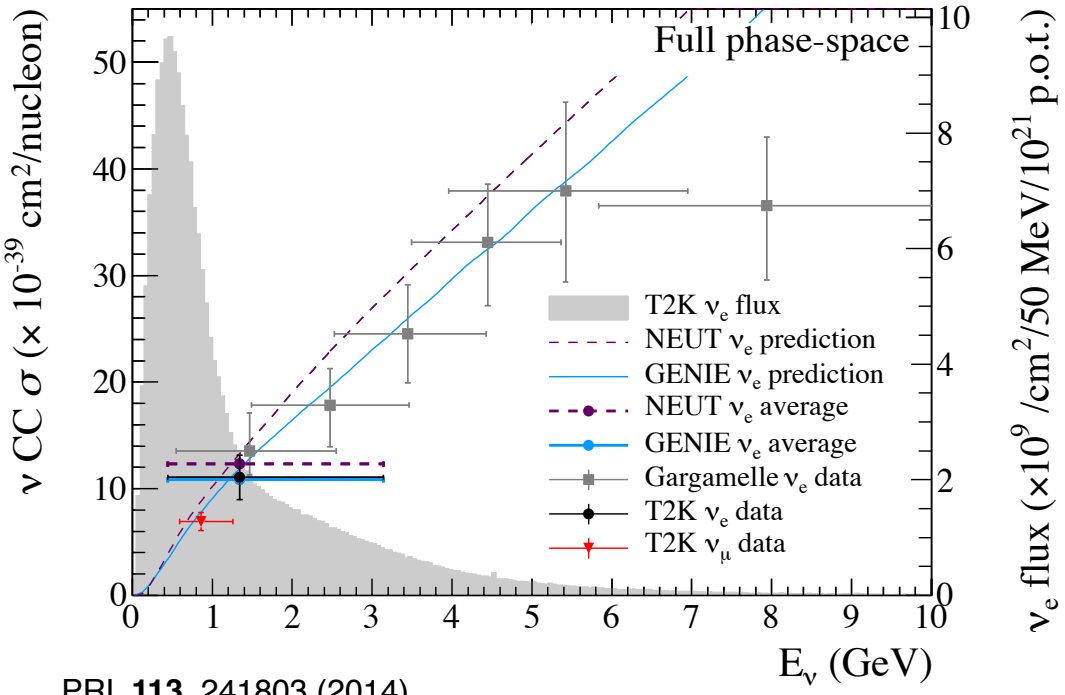
ν_μ CC Interactions in the NOνA Near Detector



- Even with a narrow-band beam, NOvA still has access to all FSI types.
- Too many Ph.D. topics here to list…
- ν_μ CC QE and CC inclusive cross section measurements are underway

ν_e + A CC Interactions in the NOνA Near Detector



PRL **113,** 241803 (2014)

- Very limited world data

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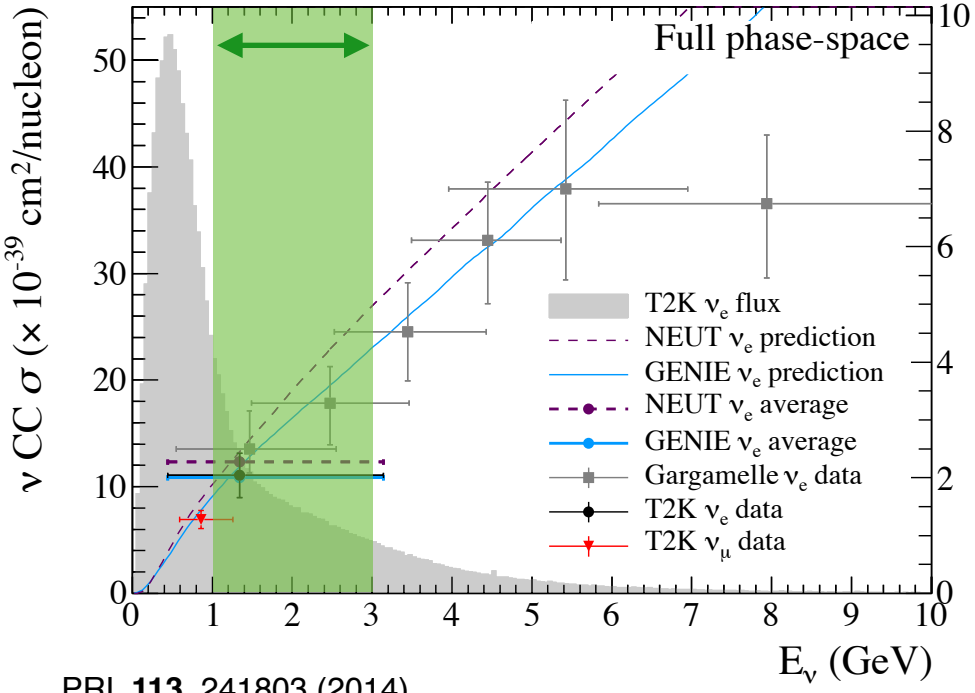
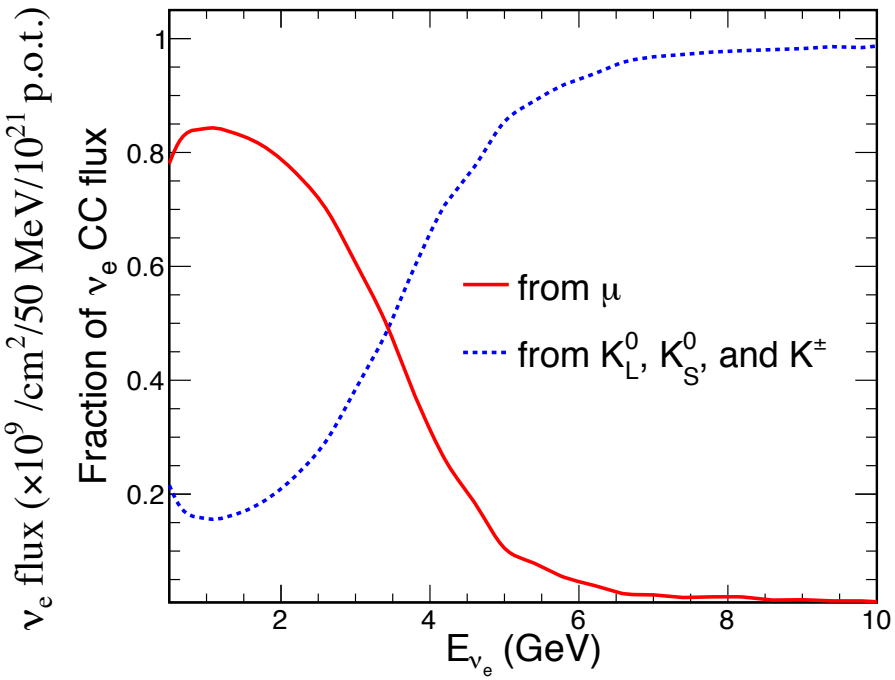
ν_e + A CC Interactions in the NOνA Near Detector



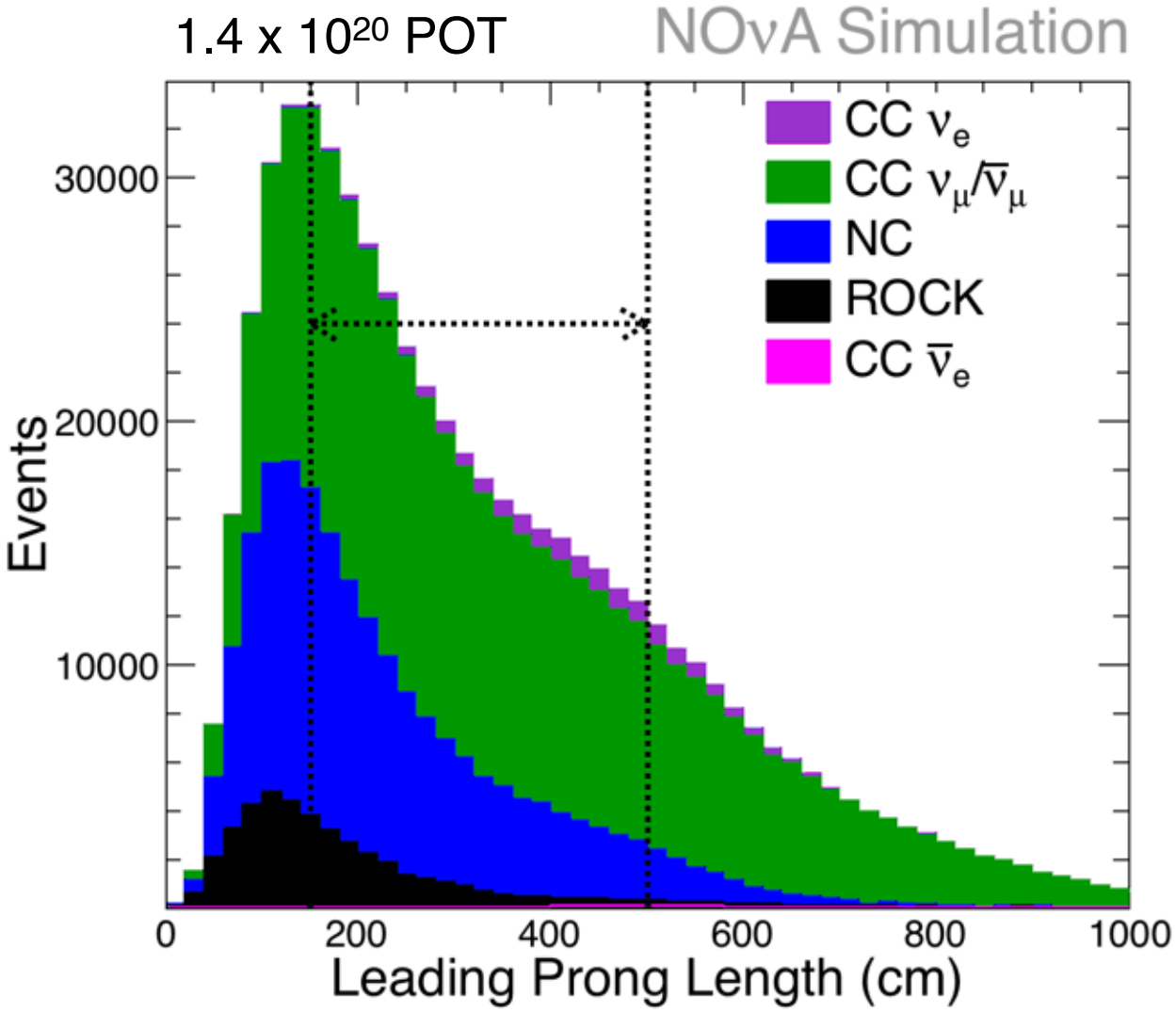
PRL **113,** 241803 (2014)

NOνA Simulation

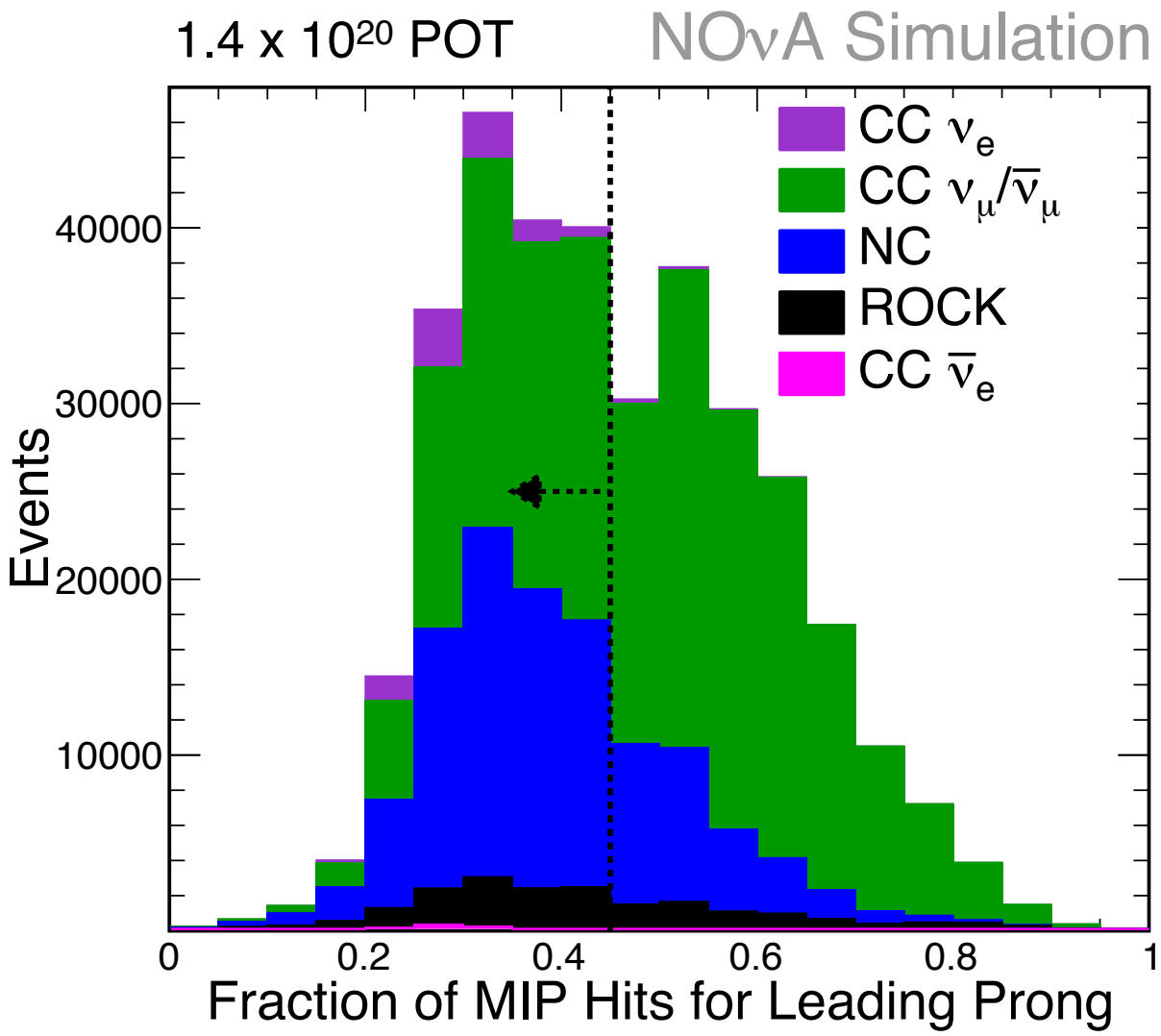


- Very limited world data
- NOvA has a unique opportunity to make a clean measurement of ν_e CC inclusive cross section
- Will restrict to 1-3 GeV range for the time being

ν_e + A CC Interactions in the NOνA Near Detector



ν_e + A CC Interactions in the NOνA Near Detector



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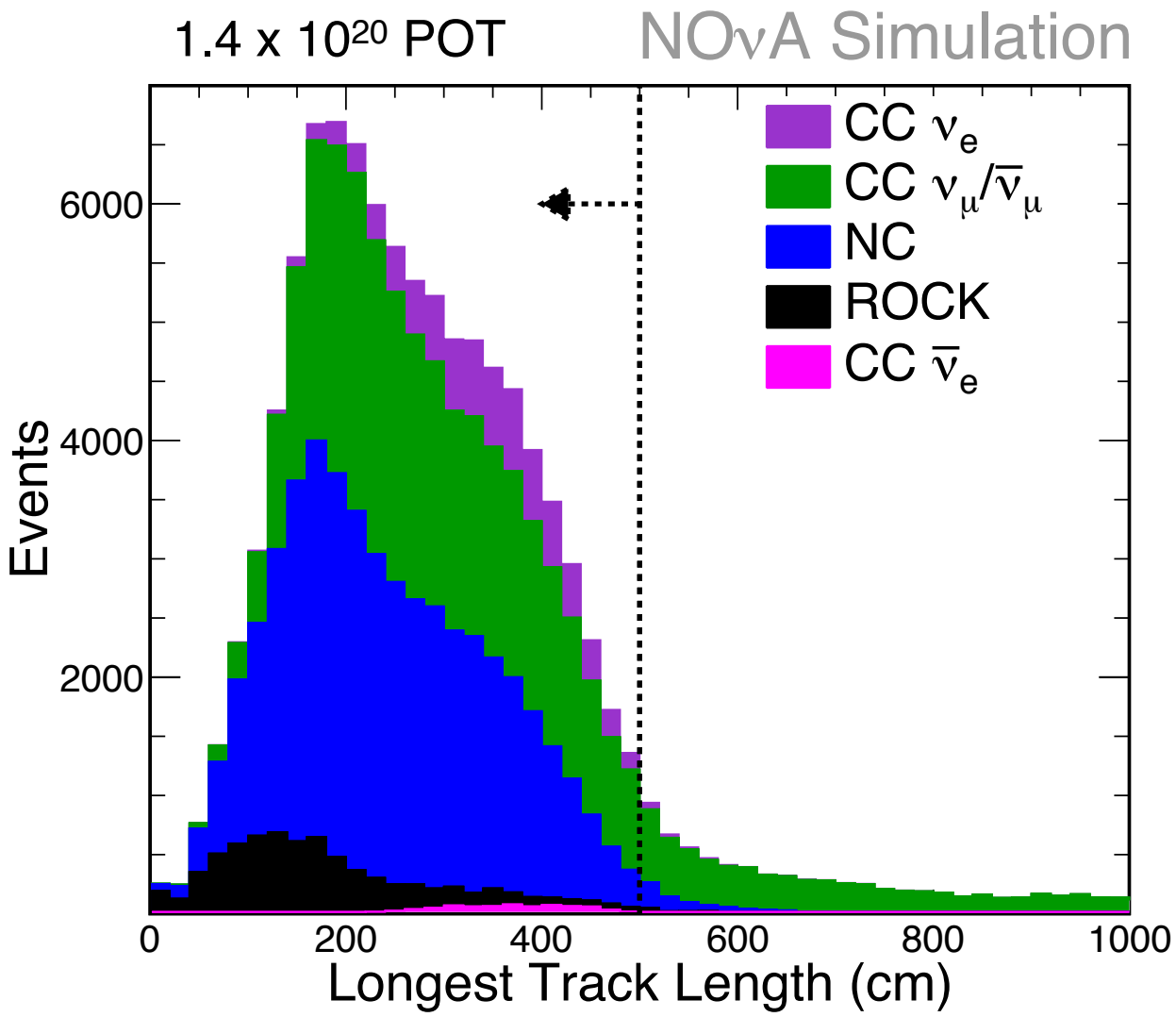

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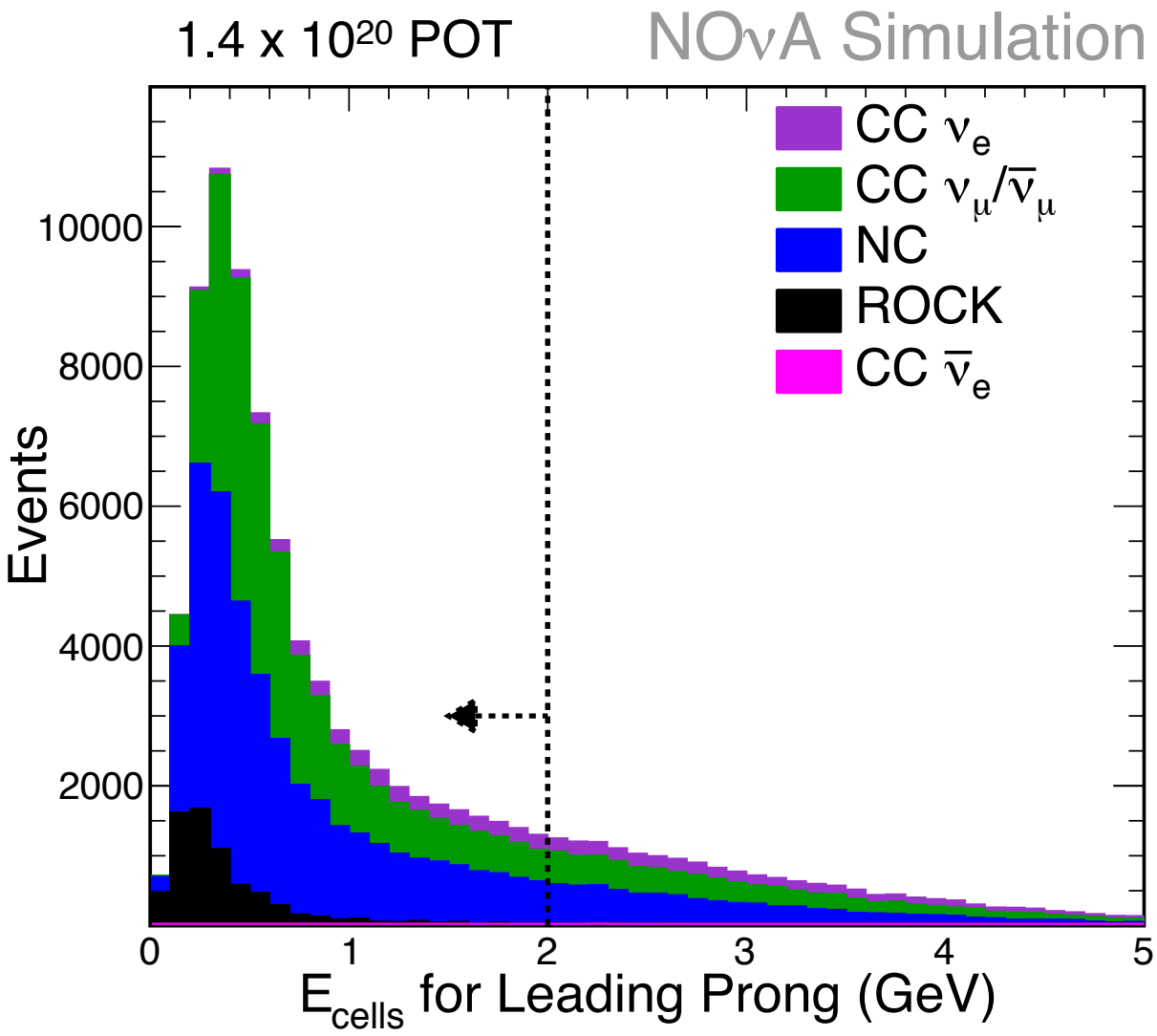

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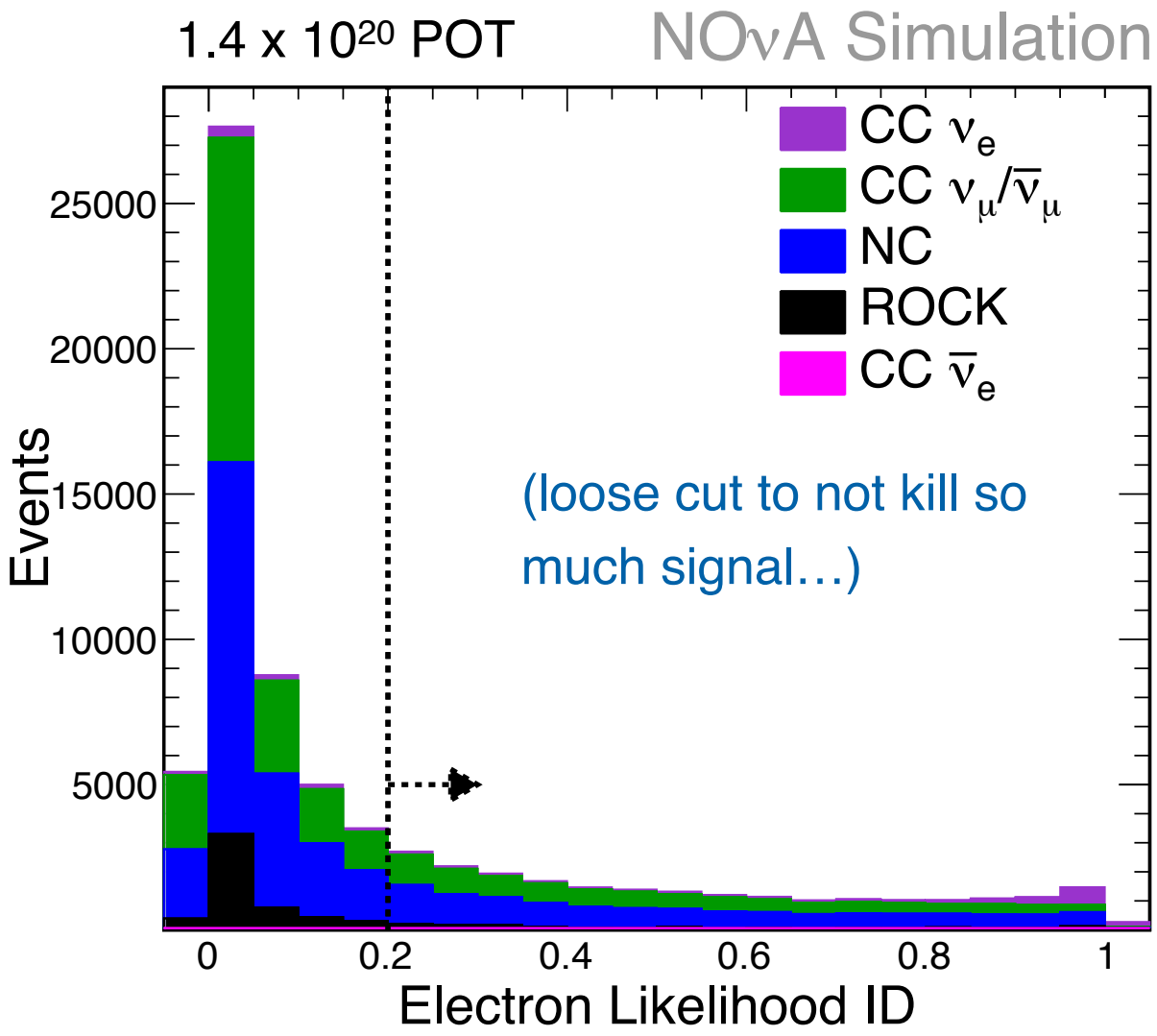
ν_e + A CC Interactions in the NOνA Near Detector



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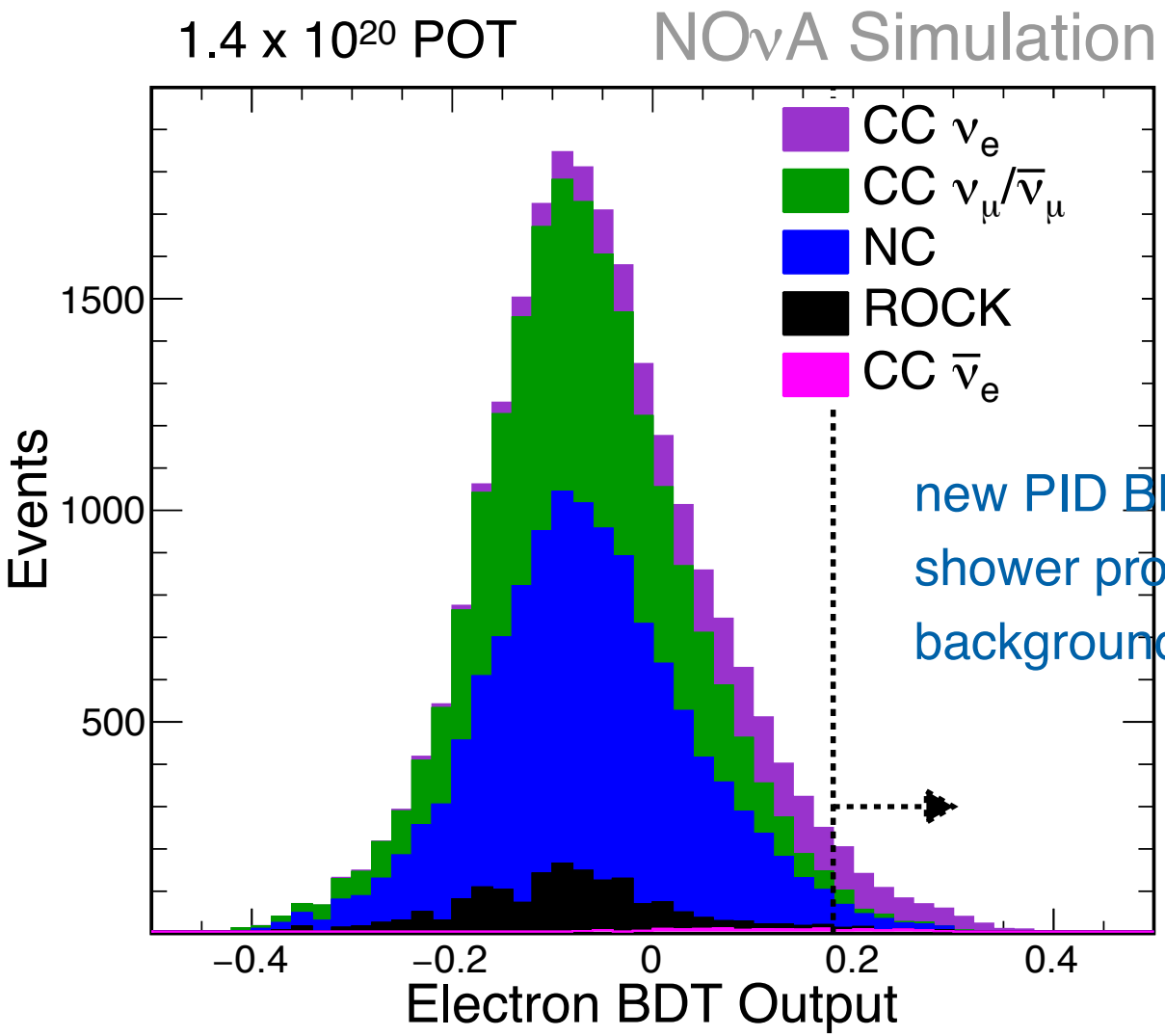

new PID BDT based on 7 shower properties to reduce backgrounds

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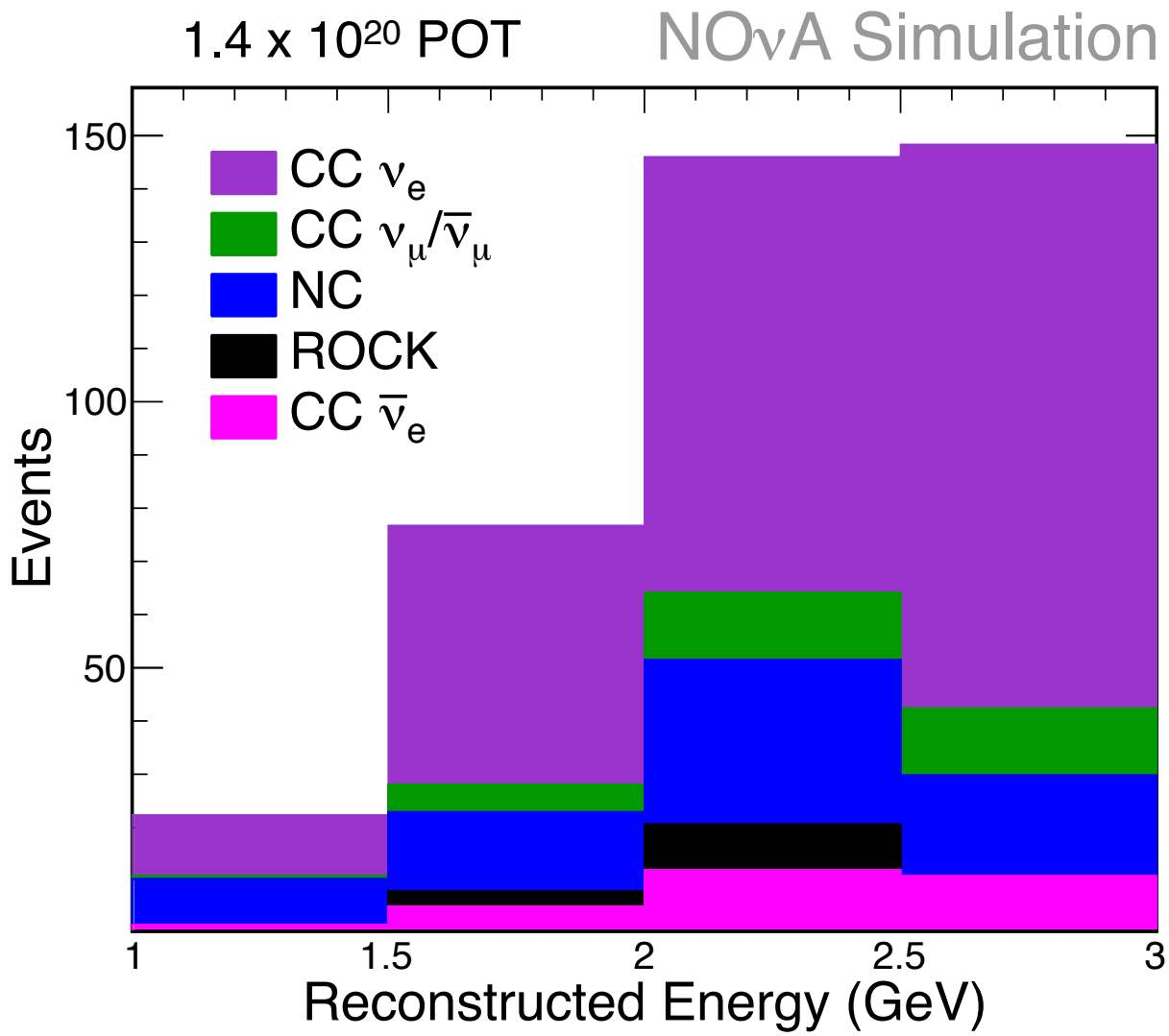
ν_e + A CC Interactions in the NOνA Near Detector



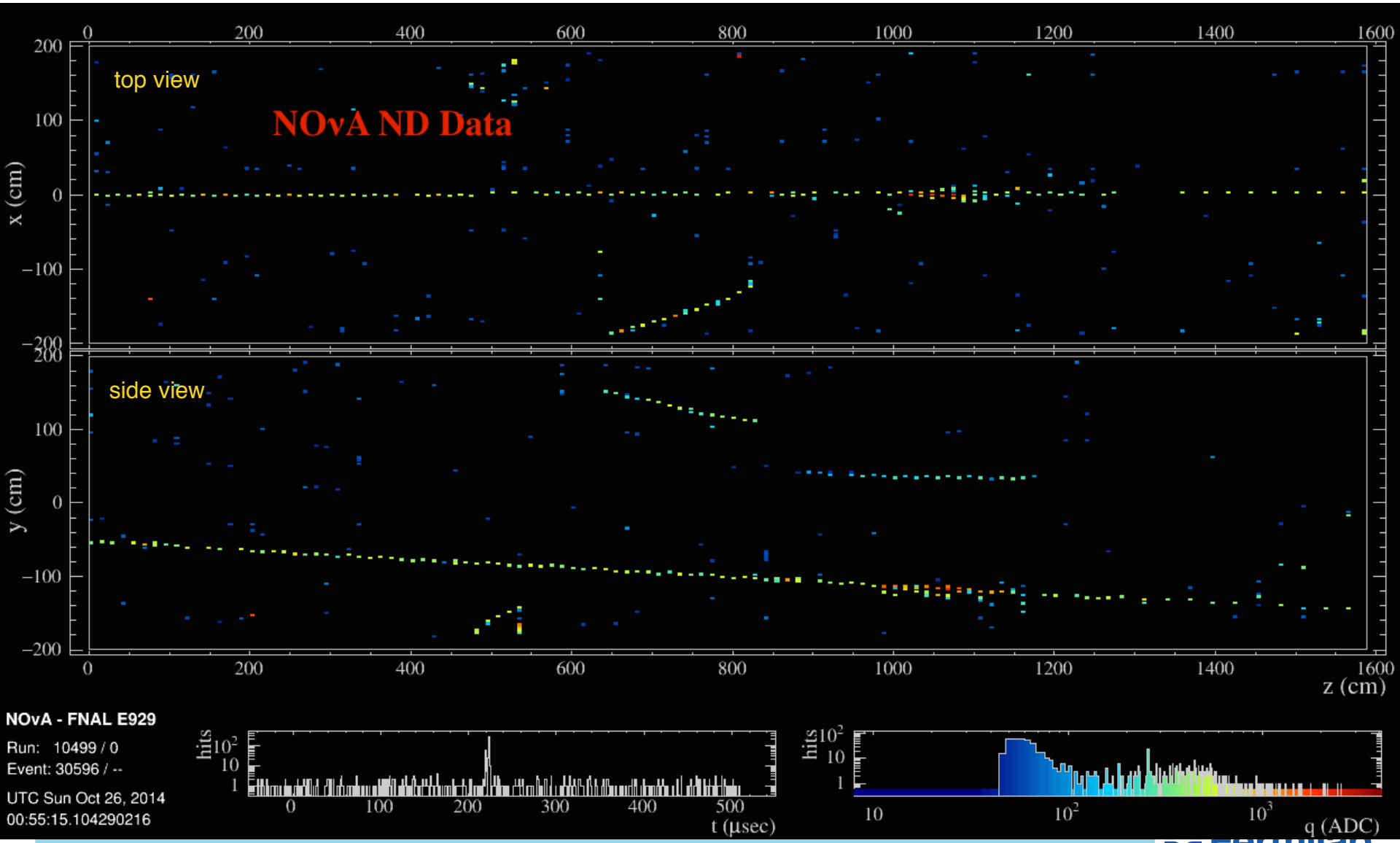
ν_e + A CC Interactions in the NOνA Near Detector

- Dominant systematics:
  - flux (~21%)
  - energy scale (10-15%)
- Flux uncertainties may be reduced via MIPP, NA61 hadron production measurements,
- Energy scale uncertainties should be reduced via improved simulations and other related ν_μ CC measurements
- Stay tuned!

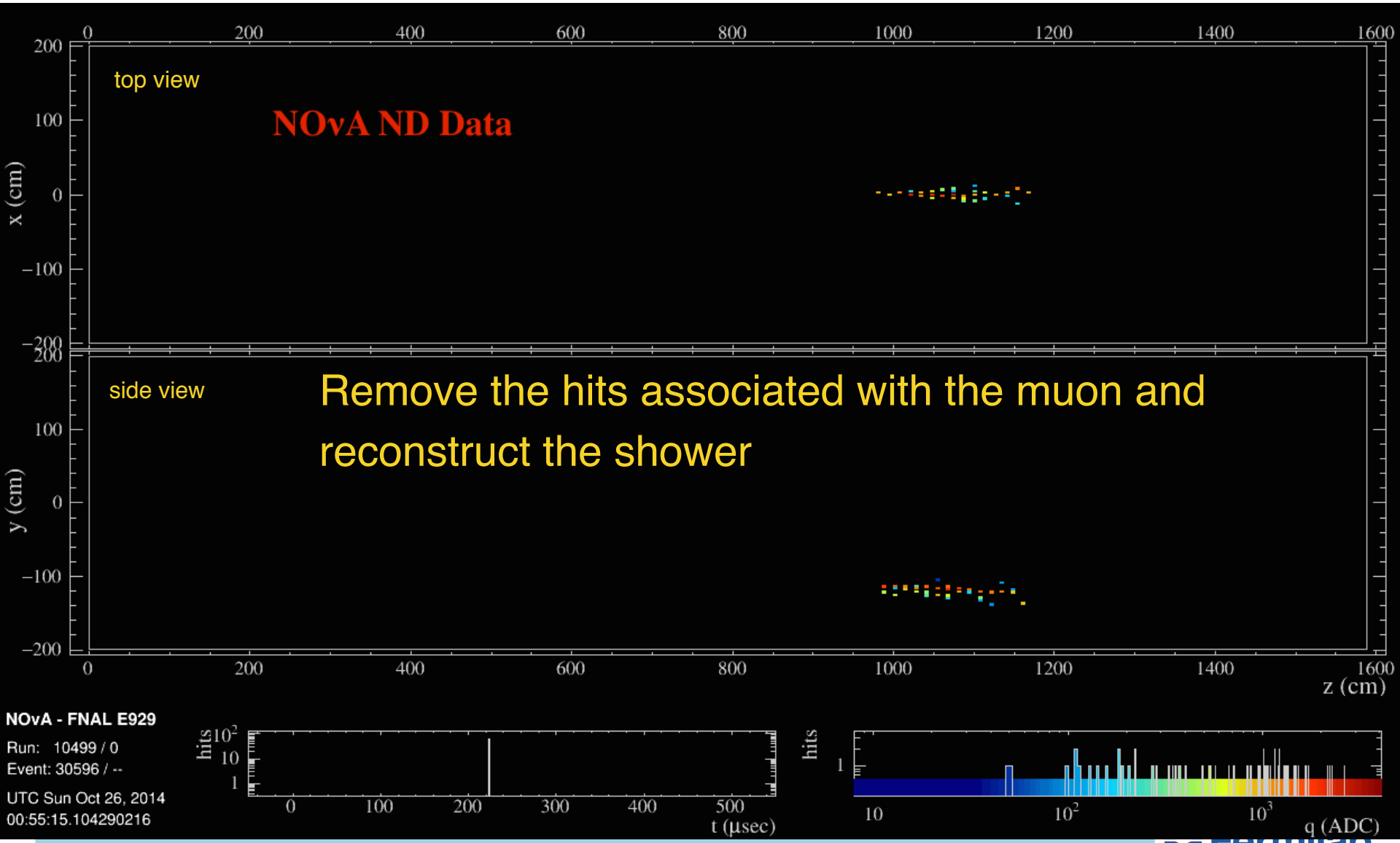
Reconstruction of shower directions

- The following analyses rely heavily on the direction of the reconstructed shower
- Data cross check using brehm showers induced by muons produced by neutrino interactions in the surrounding rock

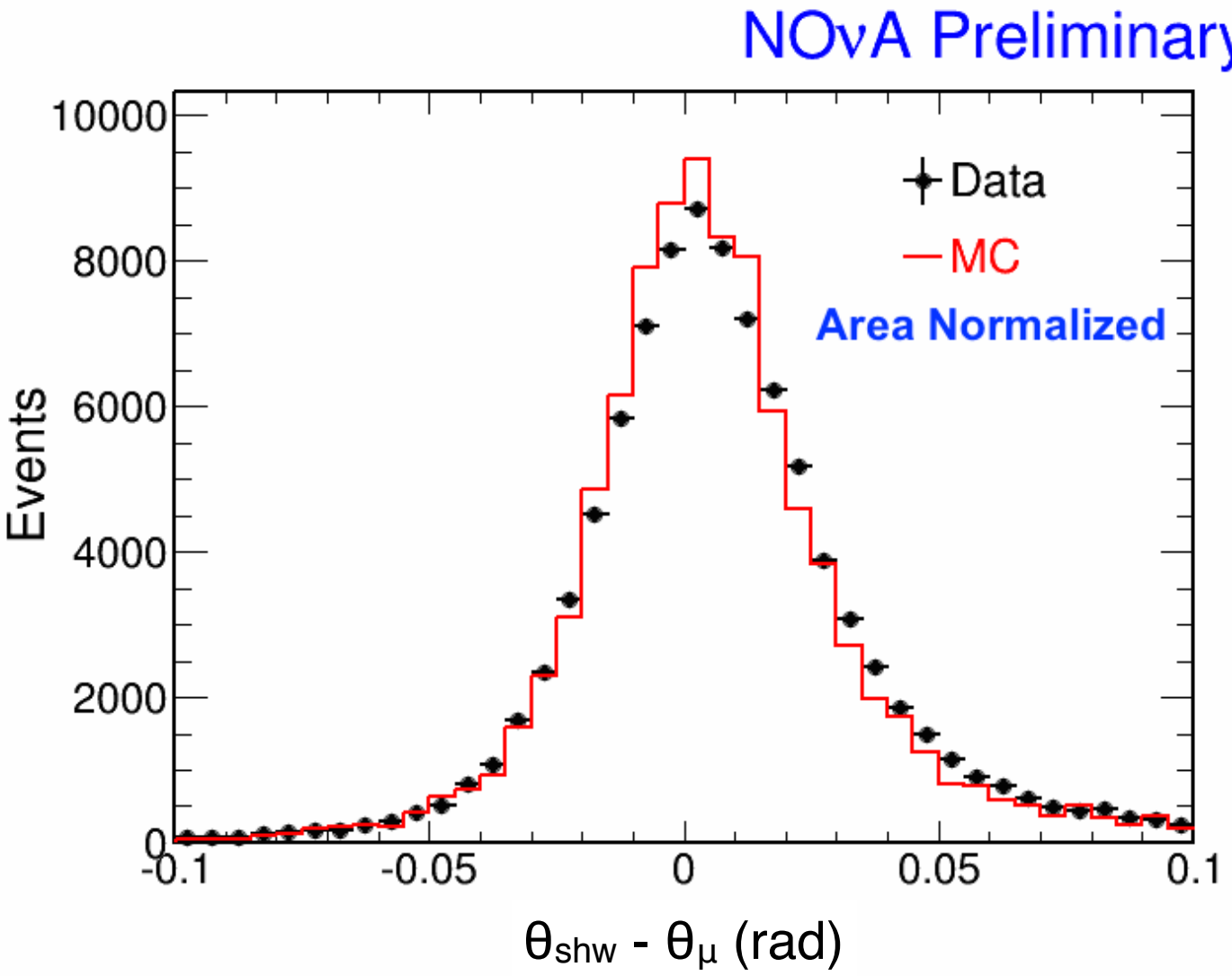
Reconstruction of shower directions



Reconstruction of shower directions



Reconstruction of shower directions



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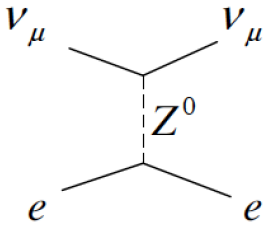
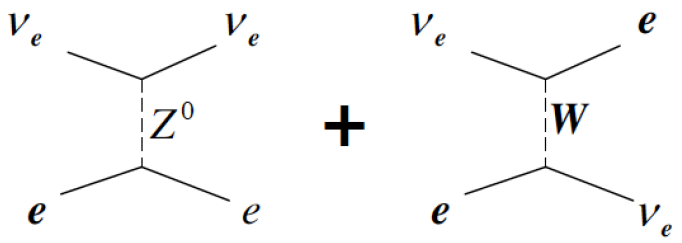
ν + e Interactions in the NOνA Near Detector





$$\nu_\mu + e^- \rightarrow \nu_\mu + e^-$$
$$\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^-$$

$$\nu_e + e^- \rightarrow \nu_e + e^-$$
$$\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$$

- Purely leptonic process, cross section accurately predicted
- Signal is very forward-going electron shower
- Can be used to constrain ν flux
- Challenge: cross section is ~10^{-4} of ν+A , need excellent background rejection

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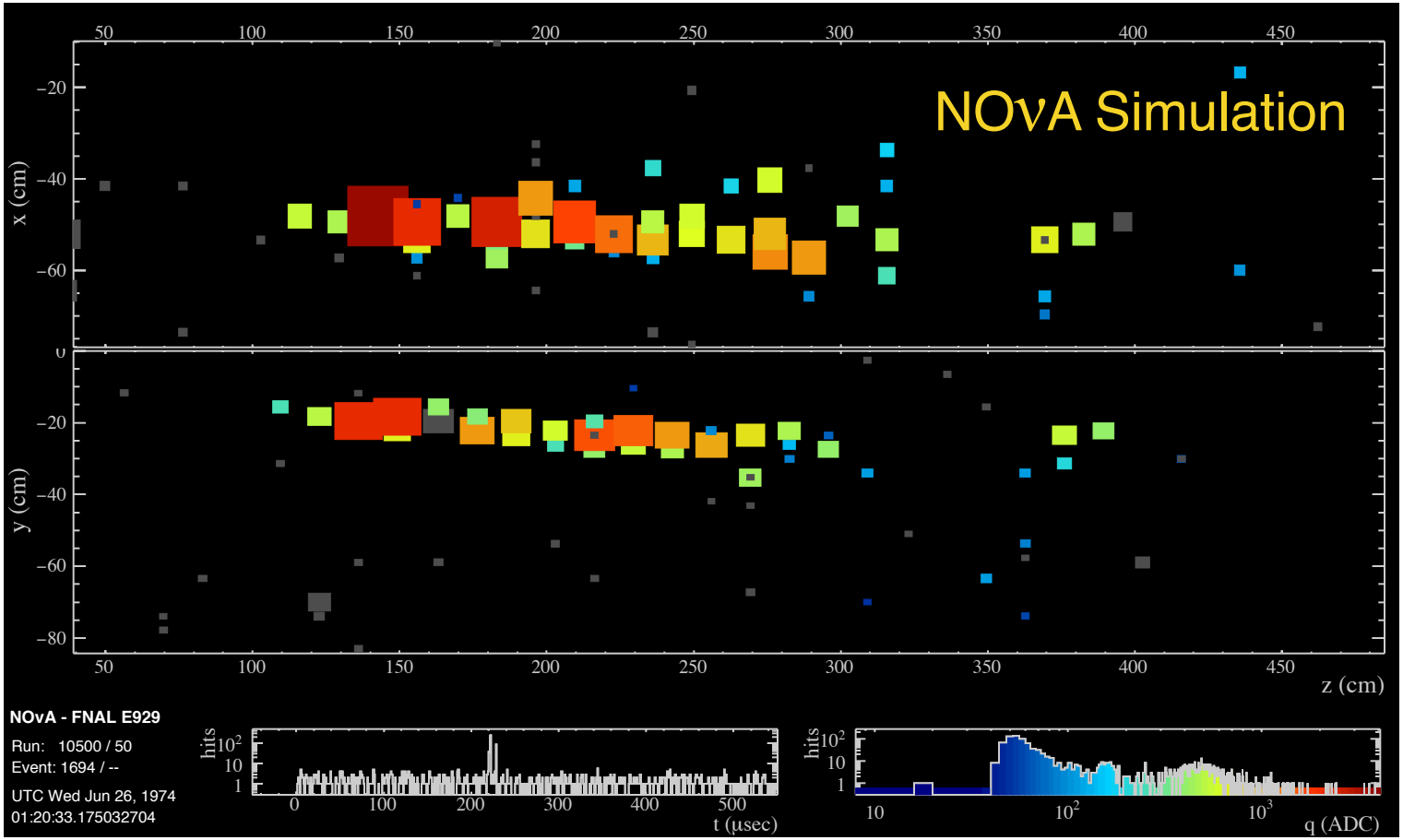
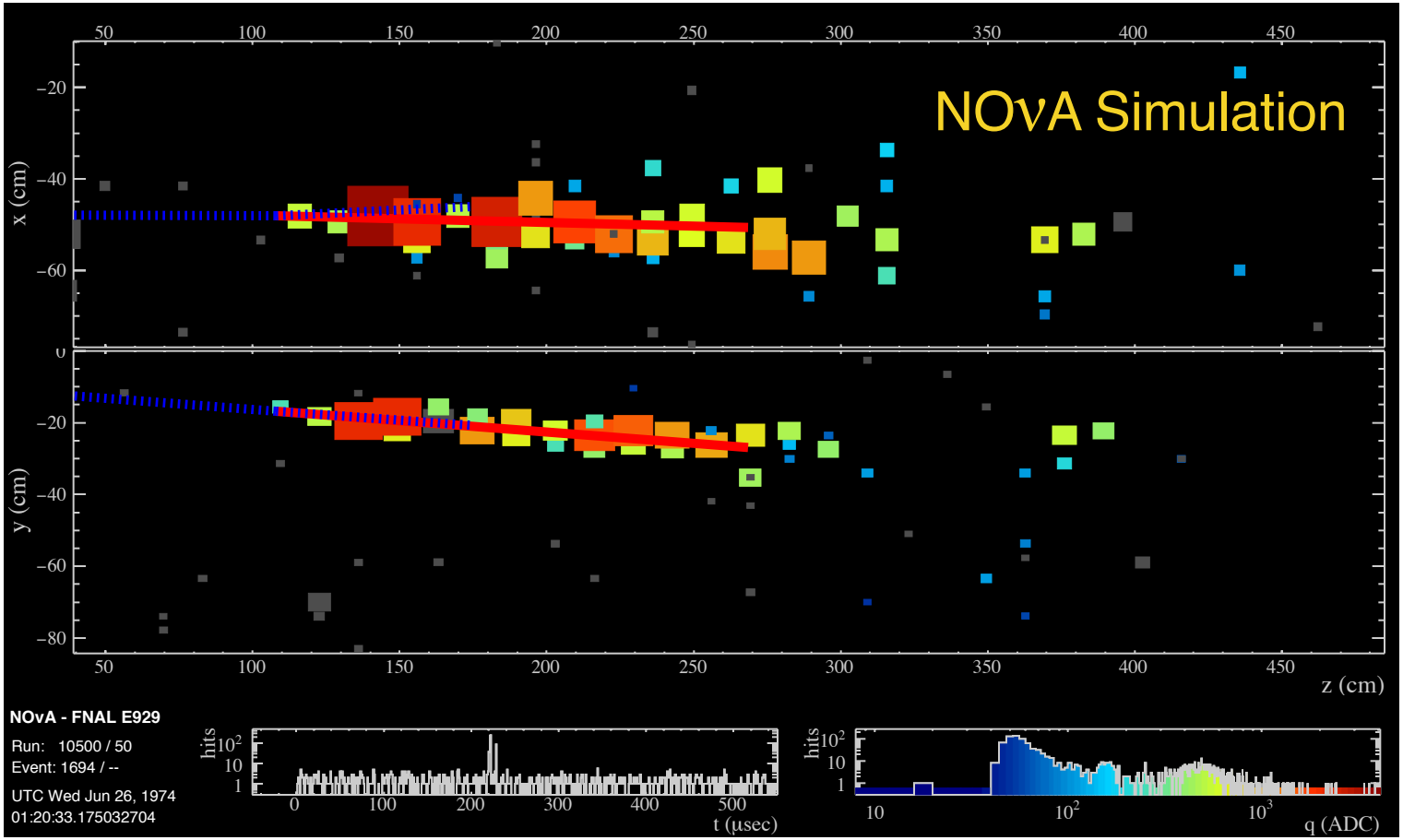
ν + e Interactions in the NOνA Near Detector



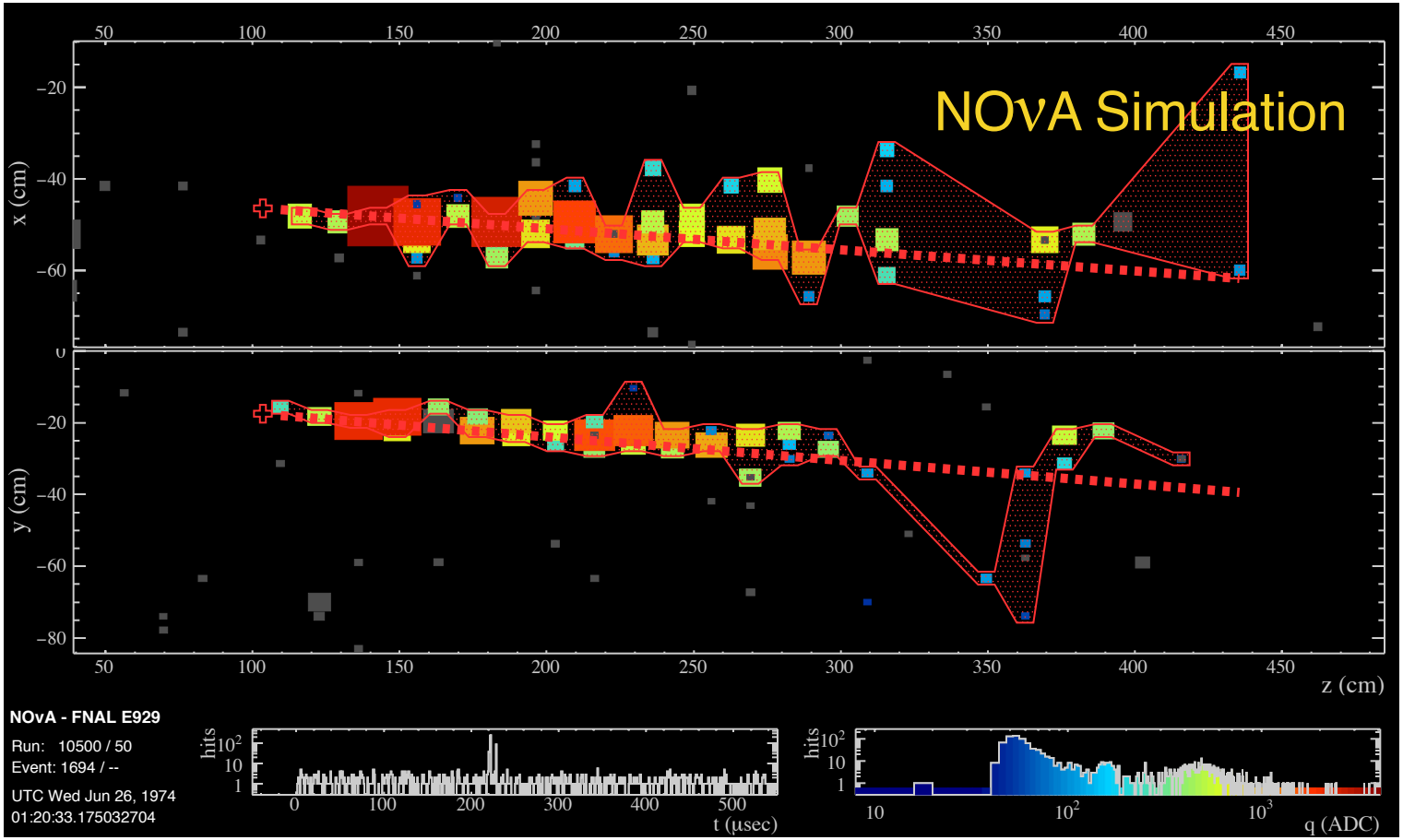
Fermilab

ν + e Interactions in the NOνA Near Detector



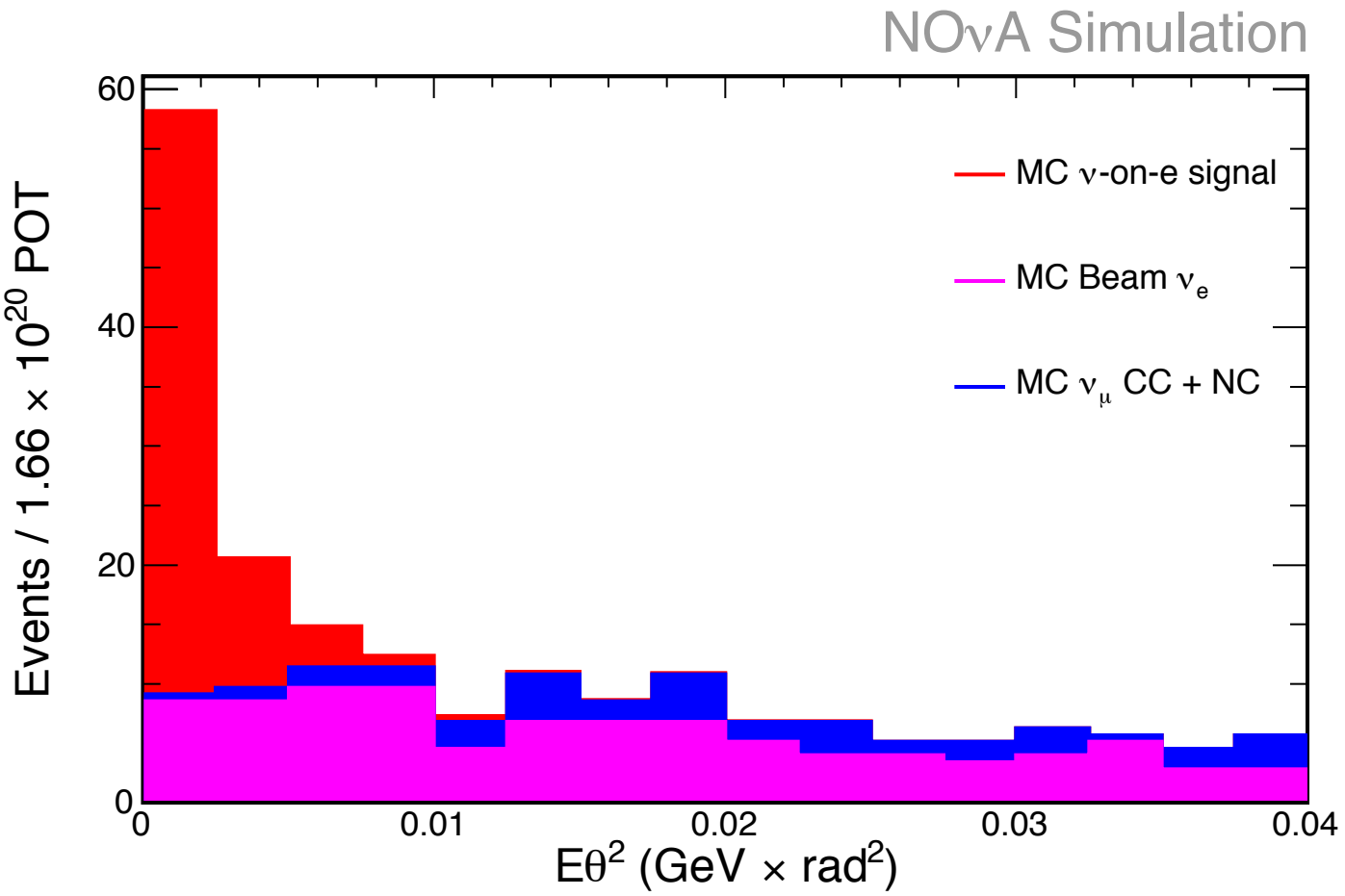
Fermilab

ν + e Interactions in the NOνA Near Detector



Fermilab

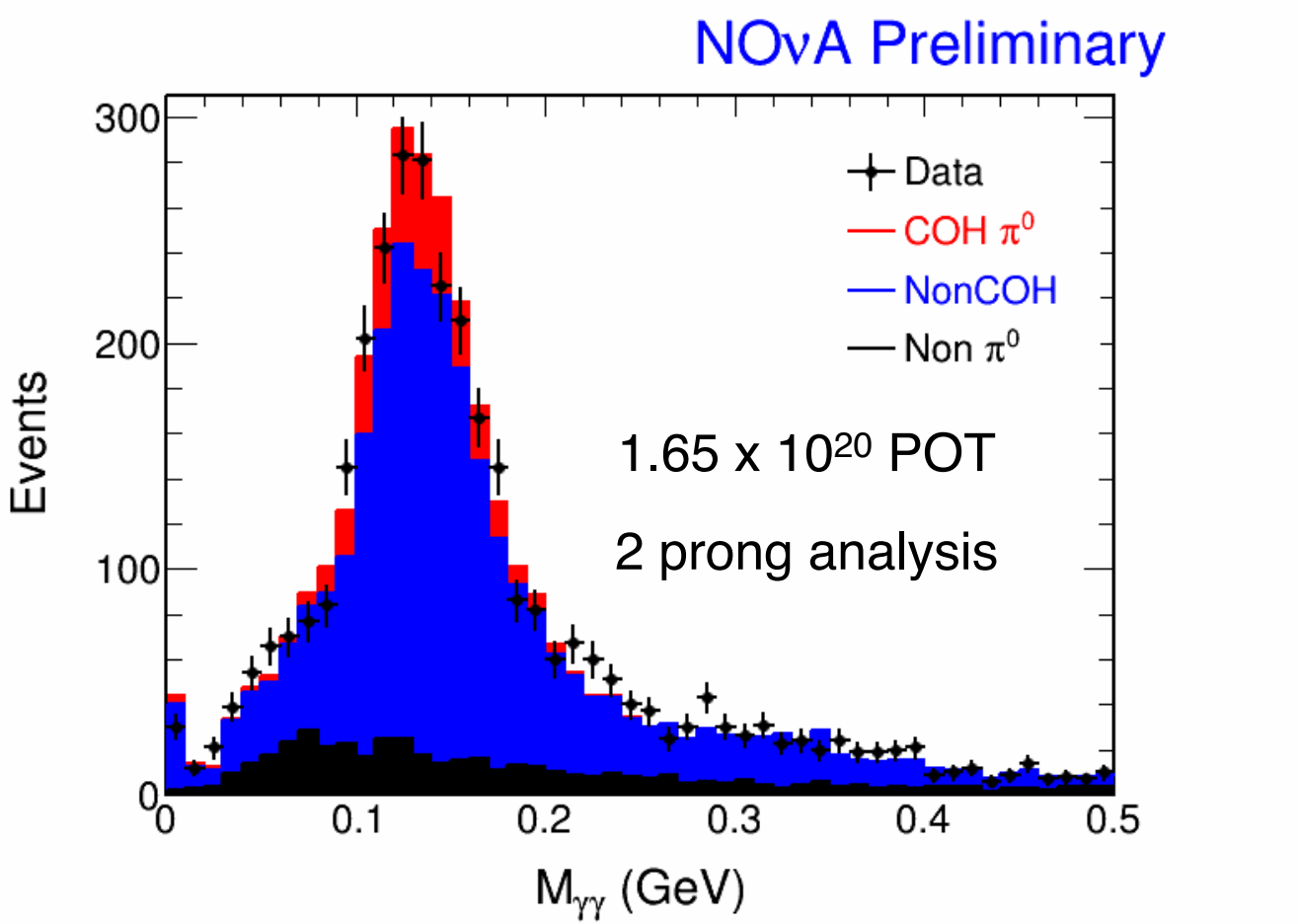
ν + e Interactions in the NOνA Near Detector



- After many other cuts…
- This represents less than 10% of our eventual data set
- $\bar{\nu}$ data will also be very useful!

Fermilab

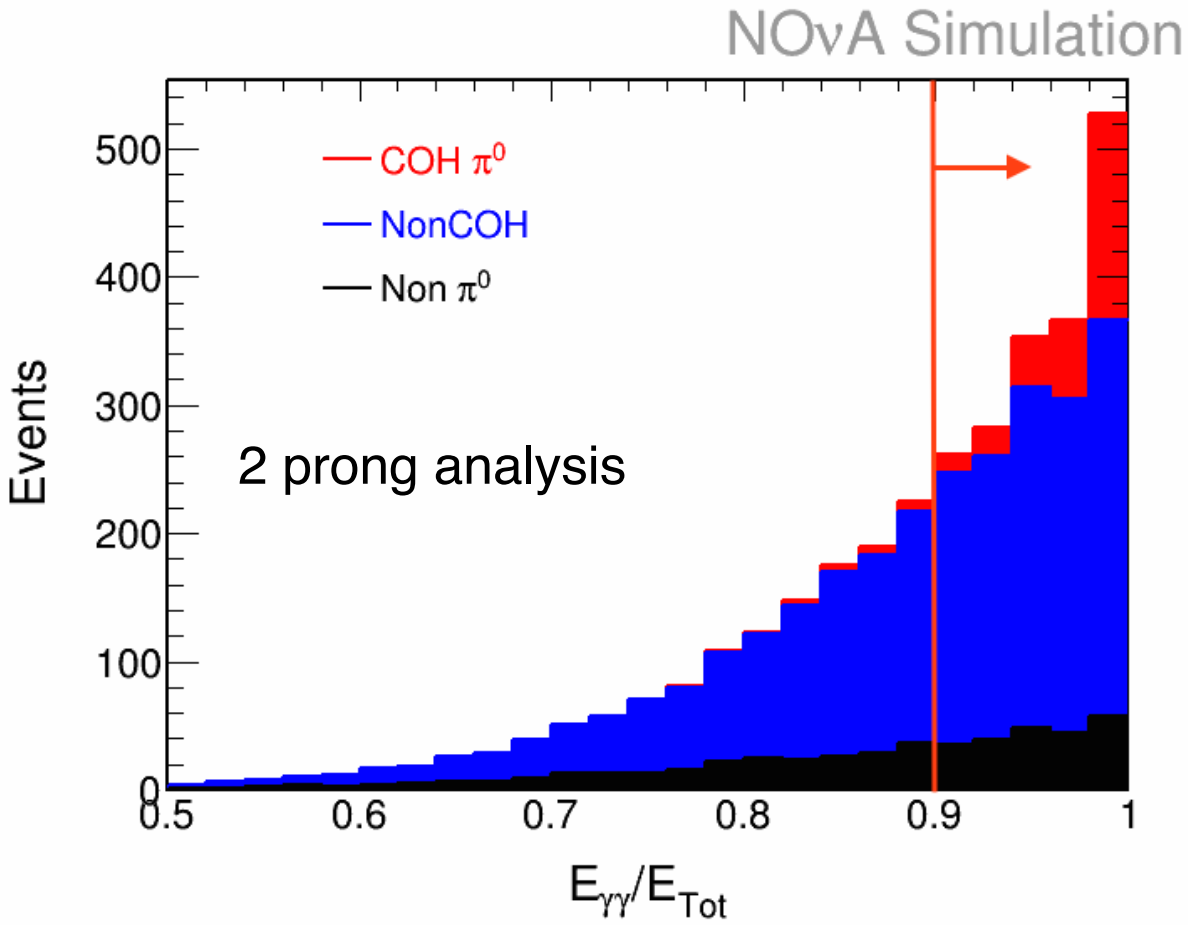
NC Coherent π^0 Production



We see plenty of π^0s (used as calibration cross check), now want to separate COH from nonCOH

Fermilab

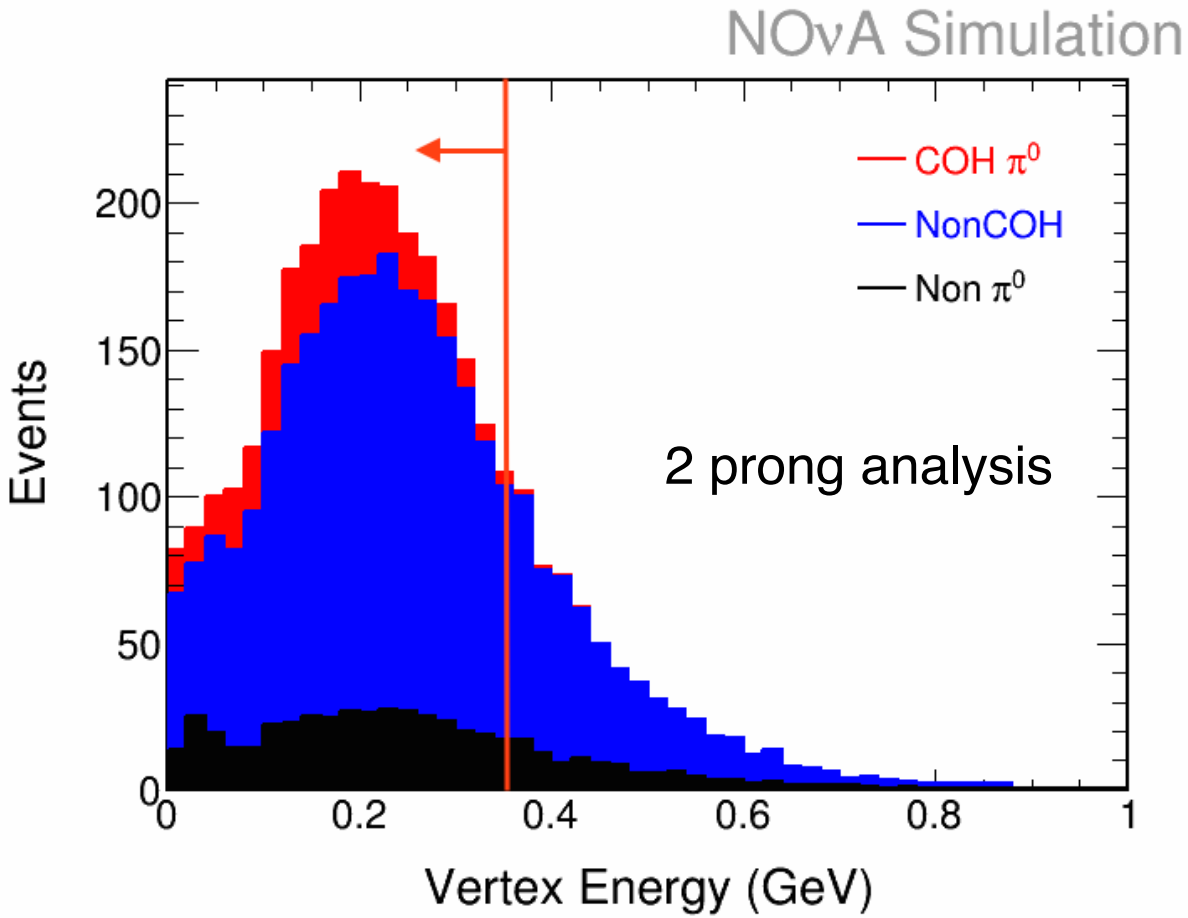
NC Coherent π^0 Production



COH interactions have only a single π^0 in the final state. All energy should be in the shower.

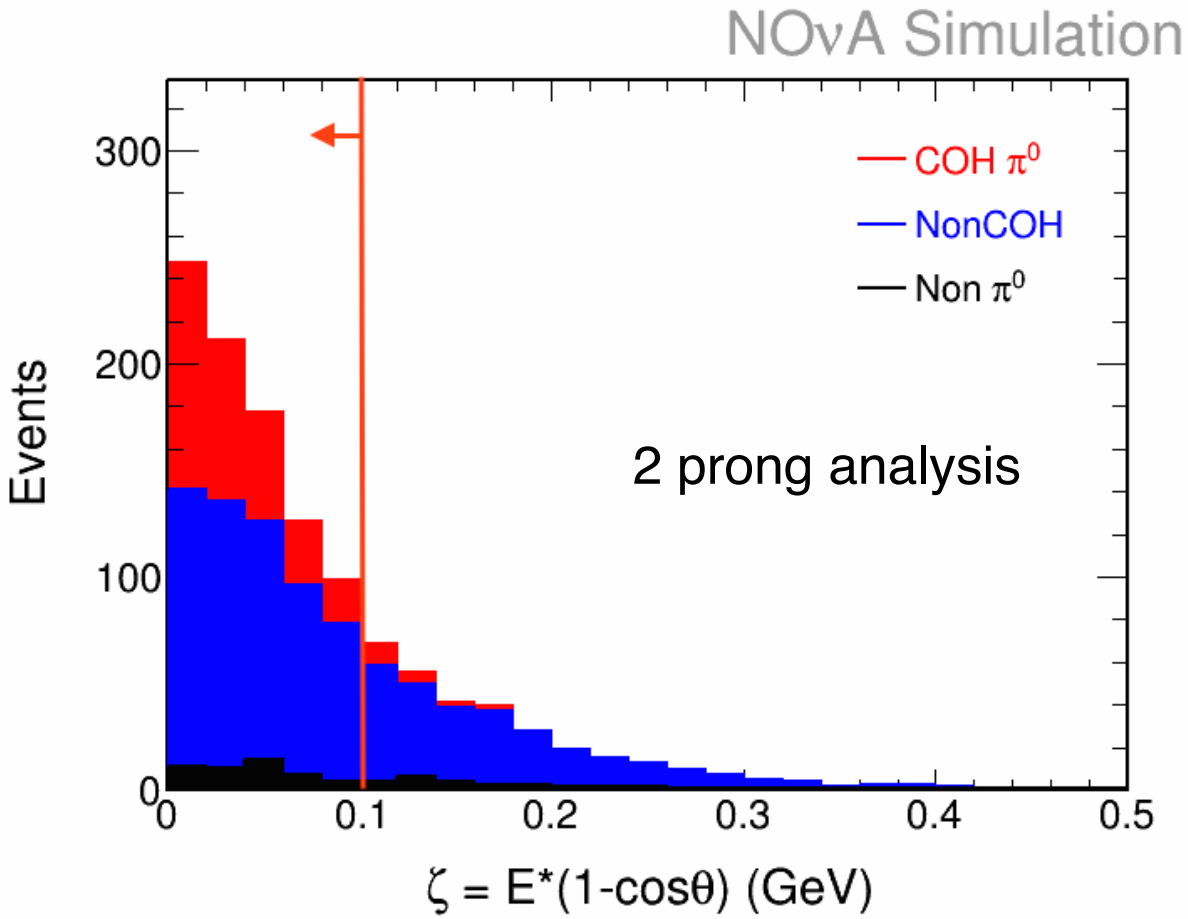
Fermilab

NC Coherent π^0 Production



COH interactions have only a single π^0 in the final state. All energy should be associated with the reconstructed vertex.

NC Coherent π^0 Production



Require event to have a very forward-going shower in the final state.

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NC Coherent π^0 Production

- Backgrounds still remain significant, focus is now on constraining the backgrounds.
- Control sample dominated by background will be used to tune background normalization and shape to *data*.
- Single prong analysis also being investigated.

Summary

- Early data from the NOνA Near Detector reinforce the need for improved modeling of neutrino-neucleus interactions.
- Future ND analyses will provide useful data for model tuning.
- Many analyses are underway:
  - ν_μ + A CC inclusive and CC QE
  - ν_e + A CC inclusive
  - ν + e (flux constraint)
  - NC Coh π^0
- Many more are just beginning
- We're looking forward to a very productive ND analysis program!

Obrigado!

Backup

The Role of the Near Detector in Oscillation Analyses